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ILLUSTRATIONS

OF

SURFACE GEOLOGY.

BY

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SECOND EDITION.

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ADDENDA

To the Second Edition.

Through the liberality of the Smithsonian Institution, Messrs J. S. & C. Adams are able to bring out a small, but new edition of this little work. I wish I had time and strength to describe the numerous additional facts respecting Surface Geology, which the last few years have put into my hands; but I can offer only a brief selection of the most interesting.

Having been engaged for several years in connection with A. D. Hager, Edward Hitchcock, Jr., and Charles H. Hitchcock, in a geological survey of Vermont, we have found the Surface Geology very interesting. The same system of beaches and terraces described in this work, extends all over the State, and they have been mapped by C. H. Hitchcock, who had special charge of this matter on most of the rivers; so that in our Report to the Government (not yet published), we were able to present a map of the terraces on the Connecticut, from its mouth, to its source, and to show numerous old river beds. My assistants have also discovered numerous additional examples of the traces of ancient glaciers on the sides of the Green Mountains, so as to leave no longer any doubts on our minds that the crest of these mountains was once a *mer de glace*, shooting forth its glaciers down the valleys on either side. On the west side, nearly on the line between Ripton and Hancock, we find bosses of rock containing drift striæ and glacier striæ, side by side; the first pointing south-westerly, towards the summit of the mountain, and the last south-westerly, down a valley.

C. H. Hitchcock has made a few measurements in anticlinal valleys, to ascertain the amount of erosion in the solid strata. In Brattleboro the result was that five thousand feet had disappeared. At Shelburne Falls, in Massachusetts, twice as much, or two miles in thickness, would be needed to fill up the gap. Other anticlinals indicate the erosion of much thicker masses, and so do the mountains of granite, which, like Ascutney, shoot up above the present surface some two thousand to three thousand feet, and which, when in a melted state, must have been kept in their place by some thousands of feet of stratified rock above them, so that we have proof here (and the same is shown by trap dykes, as is proved by Prof. Hubbard), of erosions in Vermont and New Hampshire, equal to the height of their highest mountains. Hence we are led legitimately to conclude that *the present outline of New England is due mainly to erosion*, and not to the original position of the rocks, and that *as much of rock has been swept from the surface as remains above the level of the ocean.*

In the town of Brandon, in Vermont, a remarkable frozen well exists in modified drift, consisting of gravel and sand, clean gravel, and marley clay, interstratified. The owner says that in digging the well, after passing through fourteen feet of gravel and clay, he came to frozen gravel and sand twelve to fifteen feet thick; then gravel below the frost for two feet, and then to water. It was stoned up about thirty-five feet deep, and for most of the summer of 1859 the water was not more than one or two degrees above the freezing point, and ice existed on the stones. It disappeared during September, but reappeared in December, and in January became so thick that it was necessary to go down and break it. In Owego, New York, is a similar well, in gravel or sand, seventy-seven feet deep, so hardly frozen as to be useless for four or five months each year. In Ware, Massachusetts, is a well thirty-five feet deep, which froze over in 1859. In Lyman, New Hampshire, another.

In the Ural Mountains, the Alps and the Jura, are numerous examples of *Ice Caverns*, where ice is not only preserved but formed in the summer. In all these a current of air enters at the top, and passing downward over the wet stones, produces cold by evaporation, enough to form ice, and then issues at the bottom as a cold current. Artificial ice houses are thus formed in the sides of Monte Testaceo in Rome, and elsewhere. In an old iron mine at Port Henry, in New York, the air current is found, and ice within the cavern. It seems natural to suppose that somehow or other a current of air must pass through the frozen wells, and may it not permeate the beds of clean pebbles that are interstratified in the modified drift deposits in which the wells occur? Must not air pass through them, even though very slowly, as the temperature changes? By such means might not some of the ice or frozen mud of the drift period, have been preserved to our times; being prevented from entirely melting away in summer, and increased in winter.

Recent Arctic explorations have brought to light many interesting facts respecting the Surface Geology of northern regions. They have settled the question as to the sinking of the southern part of Greenland, and the rise of its northern part, as well as of coasts 50° of longitude further west; and they have probably nearly fixed the latitude where lies the axis, along which this see-saw movement occurs. Dr. Kane thinks it not far from 77°, in Greenland; south of that point he found evidence, especially in the position of the old abandoned huts of the natives, that the coast was sinking. But to the north he found equally good proof of its elevation, as far north as the great glacier of Humboldt, and even to the northern part of Grinnell Land. At Mary Minturn river, about 79° north latitude, he counted forty-one distinct "ledges or shelves of terrace," to the height of four hundred and eighty feet; they were of "limestone shingle." These certainly indicate a recent elevation of the coast.

Capt. McClintock found numerous species of arctic shells, such as now live in the sea, up to an elevation of five hundred feet on Baring Island, as much as 50° of longitude further west than the Greenland coast, and several degrees further south. He found also the bones of a whale one hundred and fifty feet above the sea; also remnants of a deposit of pine trees, one hundred feet high. All these facts give unmistakable evidences of a rise in the coast, and when compared with the facts in Greenland, they indicate a northeast and southwest trend of the axis of oscillation.

No geologist, it seems to me, can read Dr. Kane's description of the glacial phenomena along the coasts of Greenland and Grinnell Land, and not feel that if a similar state of things once existed in Canada, New England, and other northern parts of our country, it would satisfactorily explain the phenomena of drift. Hence it is fair to presume that such a state of things did once exist here, and that drift has resulted from ice floes, icebergs, ice belts and glaciers.

McClintock describes several cases in north latitude, 74°, where bowlders seem to have been transported to the north and northwest, from one hundred to two hundred miles. It is very difficult to settle such a point in such inhospitable regions, covered most of the year with ice and snow, whose geology must of course be imperfectly known; yet if there be no mistake here, the point seems to be ascertained on our continent, from whence drift has taken a *northerly* direction, as in Scandinavia. Notwithstanding the great hardships and perils of these arctic explorations, they are certainly doing a good deal for geology.

During the years 1858 and 1859, exploring parties have been employed upon the lower and upper Colorado and San Juan rivers in California, Utah and New Mexico; and the accounts which the reports give us respecting the *canons* of that region, almost stagger our belief, though coming from unquestionable authority. Dr. J. S. Newberry, the geologist of the expedition, says of the Upper Colorado, surveyed in 1859, that "our field of exploration includes an immense labyrinth of great canons, scarcely less abysmal than those of the Lower Colorado, in which we were last year involved; *some of which are over a mile in depth*, and even more varied and wonderful in character. The sections exposed in their walls permitted me to measure and examine all the strata between the base of the carboniferous, and the summit of the cretaceous series; the latter formation attaining a thickness of four thousand feet, and occupying an immense area west of the main divide of the Rocky Mountains," *American Journal Science, March*, 1860, *p.* 208. Where upon the earth have any erosions to be compared with these been described? How do all others by the side of these seem to be mere surface scratches, and of ephemeral age?

One of the strongest objections that have been made against the views presented in this work, is, that they suppose the ocean to have stood over this continent, between two thousand and three thousand feet above its present level, during the drift period, and subsequently. Professor Ramsey, who has studied this subject so thoroughly in respect to Wales, and proved that country to have been as deeply submerged, has, since his visit to this country in 1857, presented a paper to the Royal Institution, upon the depression of North America, during the same glacial period. "During the greatest amount of submergence of the country," he says, "the glacial sea in the valley of the Hudson, must have been between three thousand and four thousand feet deep; and it is probable that even the highest tops of the Catskills lay below the water." It is gratifying to find the same conclusions on this subject, reached by this eminent geologist, which I had previously inferred from researches chiefly made in New England.

E. H.

AMHERST COLLEGE, March 23, 1860.

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PART I.

ON SURFACE GEOLOGY,

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CORRECTIONS.

A change in the arrangement of the Plates, after a part of this Memoir was printed, makes a few corrections of reference necessary.

Wherever on pages 6, 7, and 8 Plate XI is referred to, it should read Plate XII.

Page 7, line 19 from bottom, *for* Fig. 3, *read* Fig. 2.

Page 7, line 16 from bottom, *for* Plate IX, Fig. 2, *read* Plate X, Fig. 1.

ON SURFACE GEOLOGY,

ESPECIALLY THAT OF THE

CONNECTICUT VALLEY IN NEW ENGLAND.

Introductory Remarks.

It has not unfrequently happened that those geological phenomena which lie nearest and most open to observation, have been the last to engage attention. The crystalline rocks were much earlier studied than the fossiliferous; and of the latter, the older and most deeply seated were well understood before Cuvier and Brogniart turned the attention of geologists to the tertiary deposits. It was not till a much later date, that the drift deposit, although so widely spread over the surface in northern regions, received any careful examination. And the subject of terraces and ancient beaches, is only at this late period beginning to call forth careful and thorough investigations; although these forms of gravel, sand, and loam, present themselves along nearly all our rivers, around our lakes, and towards the shores of the ocean.

I do not mean that these terraces, &c., have been entirely unnoticed by geological writers of the last quarter of a century. In the writings of Dr. Macculloch, more than thirty years ago, may be found some most beautiful delineations of these phenomena, and accurate descriptions of the very remarkable and peculiar terraces, called the Parallel Roads of Glen Roy, or Lochaber, which have engaged the attention of more subsequent writers than almost all other forms of the terrace. In the year 1833, the writer of this paper, in his Report to the Government of Massachusetts on its Geology, devoted some pages to a description of the river terraces; and gave a theory of their formation, different from that usually received. But no accurate details of facts accompanied these views.

Some elementary treatises on geology have, within a few years past, presented the subject of terraces and ancient beaches. This is especially the case in the writings of Sir Charles Lyell. That gentleman, also, has given to the public, through learned societies and journals, several detailed descriptions of these phenomena in particular localities.

The work, however, which seems to me to mark an era in this department of science, both in its presentation of facts and ability in reasoning, is Charles Darwin's *Geological Observations on South America.* It must have required extraordinary industry to collect the facts, and great familiarity with geological dynamics to

arrive at the conclusions. This work was published in 1846, and directs geologists to the only true method of arriving at the truth on this subject, viz: by a careful investigation of the facts.

The work, however, which first awakened a more especial interest in my mind, probably because it came under my notice earlier than that of Mr. Darwin, was Robert Chambers' *Ancient Sea Margins*, published in 1847. Though dissenting from some of Mr. Chambers' theoretical views, I saw at once that he had given us an example of the true mode of getting at the truth on this subject. The numerous cases of the elevation of terraces and beaches in Scotland above the ocean, which this work contains, showed us that the same facts were needed in other countries. I felt desirous of throwing in my mite towards the work, so far as the valley of Connecticut River is concerned, though a bad state of health was a still stronger motive for engaging in it. But so many new views did my labors open upon me, that I have been stimulated to devote not a little time and labor to the subject of surface geology during the last seven or eight years. And I have been led to extend my observations beyond my expectations, not only in this country, but in Europe. I find the field to be a very large one; and that I have only begun to explore it. I have seen enough, however, greatly to modify, and as it seems to me to clarify, my views of the superficial deposits of the globe; and I venture to state my facts and conclusions before the scientific public.

I use the term *Surface Geology*, to embrace the results of all those geological agencies that have been in operation on the earth's surface since the tertiary period. All the changes that have taken place since that time, I regard as belonging to a single and uninterrupted formation, viz: the alluvial. The forces which were acting at its commencement are still in operation: but they have varied greatly in intensity at different times. Hence they have left various and peculiar products, of which the following are most worthy of note.

Drift unmodified.

Drift modified, which exhibits itself in the following forms:—

Beaches, ancient and modern.
Submarine Ridges.
Sea Bottoms.
Osars.
Dunes.
Terraces.
Deltas.
Moraines.

To which should be added the Erosions of the surface, from which the materials have been derived.

If we were to attempt to arrange these products in a chronological order, we might designate four periods, beginning with the oldest.

The Drift Period.
The period of Beaches, Osars, and Submarine Ridges.
The Terrace Period.
The Historic Period.

All the agencies, however, that have produced the above phenomena, are still in operation in some part of the globe; therefore, the above periods are intended to designate only the times when the different agencies were most intense, and produced their maximum effect. In a strict sense, they are contemporaneous. The Historic Period, however, merely designates the time since man and contemporary races have been upon the globe; and though it marks out an important zoological epoch, science has not yet been able to discover any correspondent geological change; though the presumption is, that one must have occurred, either local or general.

It is my purpose to go into a detailed description, in this paper, of only a part of the phenomena of surface geology, as enumerated above. I started with the intention of studying only the terraces and ancient sea-beaches in the vicinity of Connecticut River. I found these subjects, however, so closely related to other points, that to investigate a part would cast light upon the whole. The subject of erosions has specially attracted my attention, and, since these are not confined to the alluvial period, I shall treat of them in a separate paper. Unexpectedly, also, the marks of what I suppose to have been ancient glaciers, descending from the Hoosac and Green Mountains, fell under my notice; and I have devoted another short paper to an elucidation of the facts. In the present paper, I shall confine myself chiefly to beaches and terraces, with their associated phenomena, submarine ridges and old sea-bottoms. The subject of drift must, of course, receive some attention; since the other forms of detritus are mainly modified drift. But I assume that the general facts as to the phenomena of drift are understood by the reader.

At the first, I did not expect to extend my observations beyond the valley of Connecticut River. But, during the six years that have elapsed, I have travelled extensively, both in this country and in Europe, with an eye always open to surface geology, and usually with some kinds of instruments for measuring heights. The facts thus obtained, sometimes indeed but few and unimportant, I shall embrace in this paper.

It is well known that, usually, geological maps exhibit but little of surface geology; save where the drift or alluvium is so thick that the subjacent rocks cannot be ascertained. Were the surface geology well exhibited in such a region as New England, these subjacent rocks would occupy but a small space. I have appended to this paper, a few imperfect maps of this character. One represents, as far as I have been able to trace it out, the surface geology of the Connecticut valley; and others, certain spots, chiefly in that valley, much more limited. It has been an object of strong desire with me, to construct a similar map of the whole of Massachusetts; and the Legislature of the State have given me assistance to collect the facts. If life and ability to labor be continued to me long enough, I shall hope to accomplish this object. The present paper is a preliminary to such a work.

Several terms, mostly new, and necessary to a right understanding of surface geology, will need definition.

Drift is a mixture of abraded materials—such as boulders, gravel, sand, and mud—mixed confusedly together for the most part, but sometimes laminated, and occupying the lowest part of the unconsolidated strata, and lying immediately

upon tertiary deposits, where they are present, or upon older rocks, where they are not.

Modified Drift.—When drift has been acted upon by waves, or currents of water, the boulders are reduced in size, they are smoothed and rounded, their striæ are generally obliterated, and all the materials are redeposited in regular layers, being sorted into finer and coarser deposits, according to the velocity of the currents. These I call modified drift, which constitutes nearly the whole of what usually goes by the name of alluvium, and assumes various forms, according to circumstances.

In this paper, the term alluvium includes not only modified but unmodified drift, for reasons which will appear in the sequel.

Sea-Bottoms.—The bottom of the ocean, along the coast, is in many places covered by deposits of sand and gravel, left there seemingly by tidal action, and presenting often numerous ridges and depressions. Often, too, bars are formed across the mouths of harbors, producing lagoons. Hooks, also, are produced, where the currents sweep around headlands. While these deposits are beneath the waters, they go by the name of shoals. If these shoals, bays, and harbors be raised out of the ocean, although they will be exposed to the modifying influence of rivers and rains, their essential characteristics will be long preserved; and my impression is, that these old sea-bottoms may still be traced in many parts of our country, to the height of 1,000 to 2,000 feet above the present ocean.

Submarine Ridges.—By this term, I intend to designate certain ridges of sand and fine gravel that must have been formed beneath the waters, and yet are different from those ridges called shoals, and, perhaps, from any other submarine deposit described by Lieutenant C. H. Davis, in his admirable paper, in the *Memoirs of the Academy of Arts and Sciences*, "On the Geological Action of the Tidal and other Currents of the Ocean." The great peculiarity of these submarine ridges is, that they slope in two directions—towards the lake or the ocean, on whose borders they lie, and towards the country; a fact which indicates subaqueous formation. The natural ridges around Lakes Ontario and Erie, are a fine example of the phenomenon I am describing. (See Charles Whittlesey's excellent paper, Am. Journ. Sci., N. S., X, 31.) Perhaps, also, I may be able to point out one or two examples on the sea-coast.

Osars.—These are similar ridges, formed beneath the waters, by currents piling up materials behind some obstruction. Their form is very much like that of a canoe turned over. I have not been able certainly to identify any ridges of sand or boulders in our country with the osars which I saw in Europe. But M. Desor, whose opportunities for observation upon this phenomenon have been very extensive, speaks of osars as occurring along the shores of Lake Superior. I have marked four on Map No. 1, (Plate III,) in N. H., viz: in Union, at the White Mountain Notch (at Fabyans), and a little south of Conway; but they are of doubtful character.

I use the terms dune and delta in their common acceptation. The same is true of moraine, excepting that I think I have found some ancient moraines that have been subsequently modified by the action of water, whereby the coarser detritus has been more or less covered by water-worn and sorted materials.

Terraces and beaches form, perhaps, the most important feature of surface geology; and, as I have directed my attention chiefly to these, I shall go into more details as to their nature and characteristics.

It is hardly necessary to say that, though the term terrace applies to any level-topped surface, with a steep escarpment, whether it be solid rock or loose materials, it is only the latter kind which are treated of in this paper; for I shall describe only those terraces which have been formed since the drift period—not even those which may be unconsolidated in the tertiary strata.

Terraces are of three kinds:—

1. *River Terraces.*

These are the most perfect of all, and are found along the shores of almost all rivers; but especially those passing through hilly countries, and forming narrow basins with a succession of gorges.

River terraces may be subdivided into four varieties, differing in position, and probably, also, in their mode of formation.

1. *The Lateral Terrace.*—This is the ordinary terrace, which we meet along the banks of a river, often many miles in length, and sometimes even miles in width.

2. *The Delta Terrace.*—This occurs at the mouths of tributary streams, and was most obviously a delta of the tributary; but, as the waters sunk, the delta was left dry, and the tributary cut a passage through it, so as to form a terrace of equal height on opposite banks.

3. *The Gorge Terrace.*—This occurs either above or below the gorges of a stream, and is intermediate between the lateral and delta terraces, graduating into both.

4. *The Glacis Terrace.*—This is not level topped, but slopes gradually both ways from its axis—on the side next the stream much more rapidly than on the other. Outwardly it resembles the *glacis* of a fortification, and hence the name. It is usually found in alluvial meadows, and might, perhaps, be regarded as merely the uneven surface of a lateral terrace, as it is seldom more than a few feet high. But in some of the high valleys of the Alps, I found broad terraces sloping very rapidly towards the stream to its very brink, as well as in the direction of the currents, and Mr. Darwin describes the same kind of terrace in the high valleys of the Andes. Such terraces, then, I should regard as the true type of the glacis terrace, rather than those undulations of surface which we see in alluvial meadows.

2. *Lake Terraces.*

These scarcely differ from the lateral terraces of rivers. Indeed, many small lakes, and even some of the larger ones, appear to have been merely expansions of rivers, such as are now seen in great numbers in the basin of the Upper Mississippi, west and southwest of Lake Superior. (See *Nicollet's Map.*) These were formerly retained by barriers at a higher level when the terraces were formed, and, as those barriers have been worn away, the terraces have been left on their borders.

3. *Maritime Terraces.*

Perhaps I ought not to speak of terraces as existing on the margin of the sea, but to regard all accumulations of sand and gravel there as beaches. Some of these accumulations, however, are so nearly level-topped as not to differ from genuine terraces, and this is the main distinction which I would make between terraces and beaches. It is not, however, a distinction of much practical importance. At the mouths of rivers, the two varieties are often seen running into each other.

Moraine Terrace.—I apply this term to a peculiar form, not unfrequently assumed by the more elevated terraces, exhibiting great irregularity of surface; elevations of gravel and sand, with correspondent depressions of most singular and scarcely describable forms. I prefix the name *moraine* terrace to such accumulations, under the impression that stranded ice, as well as water, was concerned in their production.

Sea Beaches.

The most perfect of these are seen along the sea-coast in the course of formation. They consist of sand and gravel, which are acted upon, rounded, and comminuted by the waves, and thrown up into the form of low ridges, with more or less appearance of stratification or lamination. As we rise above the terraces along our rivers, and often on the sides of our mountains, we find accumulations of a similar kind, evidently once deposited by water, and having the form of modern beaches, except that they have been often much mutilated, by the action of water and atmospheric agencies, since their deposition. These have hitherto been confounded with drift, but they nearly always lie above it, and show more evidently the effects of some comminuting, rounding, and sorting agency—of water, indeed, since this is the only agent that could produce such effects. They evidently belong to a period subsequent to the drift, and I cannot doubt that they once constituted the beaches of a retiring ocean. The proof of this will be given further on.

I have spoken of these beaches as lying above the terraces. I mean that they are at a higher level often, but geologically they are lower. When terraces occur as well as beaches, the latter always are seen at a higher level than the former; usually forming fringes along the sides of mountains. Yet in other places rivers may exist at a much higher level, which have terraces also; and usually above them we find beaches, still retaining the same relative position to the terraces.

General Lithological Character of the Terraces and Beaches.

As a general fact, I give the following description, applicable to the terraces and ancient beaches:—

1. The most perfect terrace is an alluvial meadow, annually more or less overflowed, and increased by a deposit of mud or sand. Rarely are the materials as coarse as pebbles, except on a small scale. Yet usually they are sorted, laminated, and stratified. (See A on Fig. 1, Plate XI, which is an ideal section across a valley.)

2. Ascending to a second terrace, we almost invariably find it composed of coarser materials; or, perhaps more frequently, of sand at the top and clay at the bottom; though sometimes the sand is all removed. (See B on Fig. 1, Plate XI.)

3. Rising to a third terrace, we usually find a mixture of sand and gravel; the latter not very coarse, the whole imperfectly stratified, and also sorted; that is, the fragments in each layer have nearly the same size; as if the waters that removed and deposited the materials, had a different transporting power for each stratum. (See C, Fig. 1, Plate X.)

4. A fourth terrace is sometimes found still higher, differing from the last only in being of coarser, but still of decidedly water-worn materials. (D, Fig. 1, Plate XI.) There is another important distinction. Hitherto the tops of the terraces have been for the most part level, unless worn away by agents subsequent to their formation. But now we find their surface not unfrequently piled up into rounded or curved masses with corresponding depressions, resembling what is called a *chopped sea*, or the eminences and anfractuosities on the surface of the human brain. The depressions are not valleys, which might have been made by currents of water, but irregular cavities, often a hundred feet deep, or more, usually not more than twenty or thirty, and perhaps more frequently not over ten or fifteen. Yet the materials forming the boundaries of these depressions are always water-worn and sorted, either sand or gravel. These irregular cavities and elevations do not always appear in connection with the fourth terrace, but sometimes with the fifth and sixth. Yet I believe there is never a level-topped terrace above them (that is, older) in the same series; and they are always below the beaches. They are a singular feature in the terrace landscape, and are among the most difficult of all the phenomena of these formations to account for satisfactorily. I shall of course recur to them again in a subsequent part of this paper. (See D, Fig. 1, Plate XI.) Plate IX, Fig. 3, is a sketch taken in the west part of Pelham, in which we see the more perfect lower terraces, succeeded by others having the peculiarity of outline above described. Such sketches, however, give but a faint idea of these moraine terraces, as I now call them. They are shown also imperfectly on Plate IX, Fig. 2, taken in Russell, on Westfield river, with the Pentagraph Delineator, by Mr. Chapin, its inventor.

5. Above the irregular terrace just described, we find other accumulations of decidedly water-worn materials, generally coarser, the fragments of rolled and smoothed rock being sometimes a foot or two in diameter; yet still more or less sorted, so as to bring together those of a determinate size, or rather those not exceeding a certain size. Coarse sand, however, constitutes the greater part of the deposit, and sometimes the whole of it. Its outline is rounded, rarely with a level top for any considerable distance. Yet in its longest direction it maintains essentially the same level, and often may be seen for many miles at the same height, and more or less worn away, as a fringe along the sides of the hills that bound a valley; appearing, in fact, as if these deposits once formed the beaches of estuaries that occupied those valleys; and such I suppose they were. (See Fig. 1, E, Plate XI.)

As we rise above the most recent ancient beach, we find others at different levels, of materials less water-worn, more irregular in their form, and less con-

tinuous in the direction of the valley. They seem to have constituted shores when the waters were higher, when less land was above the surface, and consequently the waves had less power to wear away and comminute the rocks.

6. Passing beyond and above the terraces and beaches, thus lying at the bottom, and along the sides of the valleys, we reach the genuine drift deposit (F, Fig. 1, Plate XI,) consisting of materials that are coarser, more angular, and less arranged in strata and laminæ. These are strewn promiscuously over the hills, except those quite steep and high. They are also seen occasionally in the valleys, wherever the terraces and beaches have been worn away or never existed. Yet it must be confessed that it is often not possible to draw a distinction between the oldest beaches and the drift. They pass insensibly the one into the other. The large blocks of the drift are indeed frequently angular, but they are mixed with finer materials that have been ground down and rounded, either by aqueous or glacial agency; and the oldest beaches seem to be of essentially the same materials, somewhat more modified.

It is important, also, to mention that what appears to be genuine drift, is sometimes found mixed with, and sometimes superimposed upon, the beach and terrace materials. This is especially true of large erratic blocks. And it shows us that the drift agency, whatever it was, occurred in some places, after the modifying agency that formed the older beaches and terraces had been for a time in operation. Or, more probably, it was the same agency in modified forms that produced all the phenomena. Below the drift we find the consolidated strata. (G, Fig. 1, Plate XI.)

The views that have now been presented I have attempted to exhibit to the eye on Fig. 1, which is an ideal section across a valley, showing the manner in which the terraces, beaches, and drift are usually found; the newer deposits being chiefly formed by the denudation and modification of the drift which lies beneath the others. But as to the number of terraces, their relative height, &c., we find in nature a great variety, and this section is intended only to give the general impression that has been made on my mind by all the cases which I have examined.

Origin of the Materials.

1. I have already said that the beaches and terraces appear to be mainly modified drift. The agency by which the former have been produced, commenced the process of separation and comminution, carrying it at first only far enough to form the higher and coarser beaches. The work still went on with another portion, till it was reduced into finer materials for the higher terraces—and still finer for the lower terraces, until, when it came to the lowest of all—our present alluvial meadows—the fragments had been brought into almost impalpable powder, so as to form fine loam.

2. Such a work could not go forward with fragments already detached from the ledges, as was drift, without subjecting the solid rocks to erosion, wherever exposed. Accordingly a part of the materials of the terraces and beaches must have been derived from this source. How deep in any place these erosions have

been made, may be learned by ascertaining how near the bed of the stream we find drift striæ and furrows. From some facts of this sort, I am satisfied that though fluviatile erosion has been considerable in some places, even as much as 200 or 300 feet, in general no great amount of the detritus of terraces has been thus produced, except in loose materials.

Arrangement of the Materials.

1. *Stratification and Lamination.*—All these deposits are more or less stratified, and most of the finer varieties are also laminated. The lamination is not unfrequently oblique to the stratification. The former is frequently inclined some 20° to the horizon, the latter usually quite horizontal, though the strata or laminæ of clay are sometimes plicated.

The *Loess* of the Germans, or *Limon* of the French, along the valley of the Rhine, is usually represented as neither stratified nor laminated. That it is a fresh-water deposit, all admit; and that the terraces along the Rhine are mainly composed of it, I was assured by Professor Noggerath, of Bonn, as I ascended that river in his company, in 1850. That it is also more or less stratified, I cannot doubt. Indeed, so it is represented by Sir Charles Lyell. But from its composition (fine calcareous clay), we might presume that lamination would be mostly absent.

The other deposit, apparently without stratification or lamination, is what in Scotland is called *bowlder clay;* that is, clay containing pebbles and frequently quite large bowlders. Some which goes by this name in Scotland may be unmodified drift: but where it was pointed out to me, by Dr. Fleming, in Edinburgh, it appeared to be drift modified by aqueous action and deposited in the turbulent waters of the ocean. In this country the clay sometimes so much predominates that it is used for making bricks. I cannot doubt that imperfect stratification may be found in it.

And here I ought to remark, that when a deposit has been exposed to the weather, even for a short time, all traces of stratification and lamination disappear: but when fresh excavations are made in it, both these structures are distinct. By examining many such cuts, made by canals and railroads, I have frequently found the structure beautifully developed where no trace of its parallel arrangement could be seen at the surface. Even beds of pebbles, apparently thrown promiscuously together, are often found to be arranged in a stratiform manner.

2. *Sorting.*—Wherever a section is made into a terrace, composed of clay, sand, and pebbles, we see that these varieties of material are usually arranged in distinct layers, the coarser together and the finer together. The impression is irresistible on the mind, that the water, which made the deposit at one time, had only velocity sufficient to move the finest sediment: at another, sand, finer or coarser; at another, small pebbles; at another, large pebbles; and sometimes to urge along masses of considerable size. In such cases the stream chose out and carried forward the largest pebbles or blocks, which its particular velocity would raise, leav-

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ing other fragments for a time when its power should be increased. In this way have the materials been sorted out more nicely than any mechanical skill could do.

Details of the Facts.

I now proceed to give an account of the facts which I have collected respecting terraces and beaches, within the last six or seven years. I began their examination in 1849, and have since pursued it as diligently as my time and means would allow. And having, during that period, traversed several of the countries of Europe, I improved the opportunity to notice these phenomena, though it was out of my power to make very numerous measurements. I have also travelled somewhat extensively in our own country, to complete the comparisons. But it is along Connecticut river and its tributaries that I have made the most careful and consecutive observation. After reading Mr. Chambers' *Ancient Sea Margins*, I felt desirous of determining the true heights of the terraces in this valley, by mensuration. For a time I used the common levelling instruments, and thus obtained numerous sections. This method I found, however, to be so laborious, in a country like ours, where so few heights away from our railroads and canals have been ascertained, that some other method would be important, where the beach or terrace to be measured was distant from any such ascertained heights. I obtained an Aneroid Barometer; but my early trials with it were so unsatisfactory that I gave it up in despair. But when I reached Liverpool, and was desirous of visiting the mountains of Wales, I purchased another, and found the results so satisfactory in the measurement of Snowdon and Cader Idris, that I carried it with me in all my wanderings. In going to Ireland, however, the hair-spring that regulates the index, was broken by the rough usage of my luggage. It was mended in Edinburgh, but broken again before I reached Frankfort on the Main. Again I had it mended, and made use of it in Switzerland and Savoy. On my return to this country, I wished to ascertain whether the accidents to which it had been subject had affected its range. I soon discovered that they had. But instead of attempting to use the adjusting screws, I obtained from the Smithsonian Institution the loan of one of Green's Syphon Barometers, and commenced a series of observations in connection with the Aneroid. Those were at length reduced, and thus making the Syphon Barometer the standard, I ascertained the error of the Aneroid, and found that for every tenth of an inch it gave only 78.47 feet of altitude. Thus was I able to correct all my observations made in Europe, after the injury of the instrument, and the results I shall give below.

Having used the Aneroid Barometer so extensively, it might be desirable that I should go into details respecting the results, as compared with other measurements, in order to decide how much dependence can be placed upon the instrument. But these details would occupy too much space. If in my power, I hope to present them in some other form: for my own conviction is, that though this instrument cannot be depended on for nice observations, such as the mathematician needs, yet it is a most valuable help to the geologist. I think it can be depended on almost as confidently as the Syphon Barometer, except perhaps for very great altitudes:

In nearly forty observations, upon heights varying from 260 to 5000 feet, the difference between the two instruments rarely exceeded twenty feet, and in only one or two cases of great altitude, approached 100. Such an approximation to the truth, surely the geologist must regard as of great value, especially as the observations can be made with so little inconvenience and delay.

One of the most serious drawbacks upon this instrument, as appears to me, is the difficulty of adjusting it, or of ascertaining its range. In either case several observations must be made upon heights of several hundred feet. This is great labor for every turn of a screw. My experience leads me to conclude that to resort to the air-pump in such cases is not reliable.

Former Basins in the Connecticut Valley.

Originally, when the river stood at a higher level, this valley consisted of a succession of basins, or expansions in the stream, separated, or perhaps connected by ridges, through which gorges were cut, and deepened by the river alone, or with the aid of the ocean. At present, so deeply has the bed been worn down, that these narrow lakes or ponds have disappeared. But they have left evidence of their former existence by the terraces on their borders. The following ancient basins are well marked.

1. From the mouth of the river to Middletown, a distance of twenty-five miles, it is bounded by steep and rocky hills, with a narrow meadow occasionally. Where the river enters this mountainous region, just below Middletown, the gorge is the narrowest: but in its whole extent it has every appearance of having been formed by the joint action of the river and the ocean.

At Middletown the first, the longest, and the widest of these basins commences, and extends to Mount Holyoke, in Hadley, a distance of fifty-three miles. On the west side, however, the high land opens to the southwest of Hartford, so that on the line of the Hartford and New Haven Railroad, the summit is only a few feet above Connecticut river. It is certain, therefore, that when the river chose its present bed through the rocky region below Middletown, that bed must have been excavated nearly to its present depth; otherwise the water would have chosen the valley of the railroad in its way to the ocean. The passage through the mountains must have been lower than through Meriden, &c., to New Haven.

At Enfield, in this basin, the river has cut through a sandstone range of considerable height. The highest terraces, however, rise above the rocks in most places; yet, during the deposition of the lower terraces, the long basin above described must here have been divided into two of nearly equal size.

2. The second basin extends from Holyoke to Mettawampe (Toby,) in Sunderland, and Sugar-loaf, in Deerfield. From Holyoke, this basin must have extended southerly along the west side of Mt. Tom, and the other almost continuous trap ranges that extend to New Haven. Through this valley runs the canal railroad from New Haven to Northampton. But nowhere is this valley more than one hundred and thirty-four feet above the Connecticut at Northampton, and this is not so high as some of the terraces.

The second basin, also, extends northerly from Sunderland, on the west side of

Sugar-loaf and Deerfield Mountain, through Deerfield, Greenfield, and Bernardston. Here it joins the fourth basin of the Connecticut in the west part of Northfield; so that the second and fourth were one basin when the higher terraces were deposited. On its west side, this second basin must have been not less than one hundred and ten miles long.

3. The third basin extends from Mettawampe to the mouth of Miller's river, in the northeast part of Northfield. It is narrow, and not more than eight or ten miles long.

4. The next basin reaches from the mouth of Miller's river to Brattleborough. Some of its higher terraces extend across the barrier into No. 3, and also, as already stated, into No. 2, in Bernardston. Though seventeen miles long, it is narrow.

5. From Brattleborough to Westminster, seventeen miles, the bed of the river may be considered as a deep gorge through the mountains, similar to that south of Middletown. Through Westminster to Bellows Falls, embracing Walpole also, is a short, but very distinct basin, five miles long, with numerous terraces. Terraces also exist in most parts of the gorge, but they are narrow.

6. The next basin extends from Bellows Falls to North Charlestown, fourteen miles, where the mountains close in upon the river, as at Bellows Falls. Yet some of the highest terraces, at both extremities, pass over into the adjoining basins.

7. I regard the next basin as extending from Charlestown to Ascutney Mountain in the south part of Windsor, ten miles, although some of the terraces extend northerly into the next basin. Yet I cannot doubt, but that this mountain once formed a gorge.

8. The basins become less distinct as we ascend the valley, and I have not studied them as carefully in its upper part. I should say that we might regard an eighth basin as reaching as far as Fairlee, although the hills several times crowd closely upon the river south of that place.

9. From Fairlee, through Haverhill to Bath, the valley is wider, and the terraces numerous and distinct. This basin may extend beyond Bath, which is the northern limit of my examinations. This spot is two hundred and ten miles from the ocean in a direct line along the rivers.

On the map of the valley (Plate III,) accompanying this paper, I have marked the above basins more distinctly probably than facts will justify. But in the absence of all accurate delineations of our topography on the published maps of New England, I thought it would not be improper to represent elevations that do actually exist, in order to make myself better understood, even though they be more *prominent* than in nature.

I would here take occasion to remark, that the most serious obstacle to my progress in these investigations has been the want of accurate maps of the districts explored. Frequently have I spent the day (and the same experience is fresh in my mind as to older rocks) and have got a clear conception of the terraces, beaches, and hills in a considerable district. But on opening my map to delineate the same, I have often found, to my discomfiture, that no such region exists on the map as existed in my mind, and which I found in nature; and hence the greatest inac-

curacy must be the result, and often total discouragement. For I should thus be charged with errors of observation by future geologists, when the fault lay solely in the maps. Massachusetts is the only State in New England that has constructed an accurate map of its surface. And in that State the topography was omitted till near the close of the survey, and then hastily observed; so that it only presents us with insulated hills and ranges, as if they rose out of a level surface; whereas, no idea is presented of the longer and broader features of the country; the comparatively low region, for instance, of twenty miles from the coast; the valley of Worcester, of the Merrimack, of the Connecticut, and the deep valleys of Berkshire. Imperfect maps are one of the great disadvantages under which American geologists labor, of which the European geologist knows but little. And it must be a long time before the matter is much mended.

Basins on the Tributaries.

The tributaries of the Connecticut exhibit successive basins of the same general character as those above described. But there are two of unusual importance, which I have examined. One is on the Agawam river, in Westfield, and the other on Deerfield river, in Deerfield. In the latter basin especially, we have an epitome of most of the facts concerning river terraces and changes in the beds of rivers. That spot I have, therefore, studied with care, and shall present a separate map of its features, and also of the Westfield basin.

Of some other peculiarly interesting places in respect to their terraces, I shall, also, present maps, on a larger scale than the general one. One will be given of the terraces at Bellows Falls, another of those in Brattleborough, and a third of those on Fort river, in Amherst and Pelham.

Mode of Representing the Terraces and Beaches.

On the general map of Connecticut river, from its mouth to Wells river in Vermont, a distance of two hundred and ten miles, I have attempted to exhibit the principal terraces by colors. There are many smaller ones, however, omitted; nor have I attempted to give the true width of the terraces with any degree of accuracy. Only where the basins are the widest, there I have represented a greater breadth of terraces. To give the terraces with entire accuracy, over so wide a region, would require a great amount of labor in observation, and then it would all be useless, because of the great imperfection of our present maps. All I have attempted, therefore, is an approximation to the truth. In the vicinity of my residence (Amherst) I have delineated the terraces with more accuracy, I hope. But in some parts of the river, especially its southern aud northern limits, I have not been able to examine with the care which would have been desirable. I trust, however, that my maps will answer for all the purposes I have in view. This I believe is a first attempt of this kind, and I have been led to feel how desirable a work it would be to present a map, on a similar plan, of all the terraces, beaches, drift and other forms of surface geology in the northern parts of our country. In the vicinity of Amherst I have attempted to show what I conceive would be a desirable

map for the whole country. But the work would be Herculean, even for New England. Yet if I were a younger man, I should have the ambition to attempt it.

The colors on all the maps are the same for the same terraces, reckoning upward from the river. The lowest meadow I call the first terrace, and then count them upward; thence it follows, that the same color does not always represent terraces of the same height, since they vary in this respect on different streams; and, in general, the size and height of the terrace correspond to the size and height of the river.

As to the beaches, I represent them all by one color, as I have not explored them with sufficient accuracy to enable me to make any correct distinction between the higher and the lower, nor do I know of any important object to be accomplished by such a distinction.

1. Sections of Terraces and Beaches.

The larger part of the terraces which I have measured, I have also shown by sections across them, down to the level of the rivers on which they are situated. This will give a clearer idea of their relative size than description can do.

Tables of their Heights.

To save prolix details, I have thrown together into a table at the end of this paper the heights of all the terraces and beaches which I have measured; their heights above the river on which they are situated; and usually, also, above the ocean. The manner in which the heights were obtained is also indicated. When measured by levelling, no mark is attached; when by the Aneroid Barometer, the letters A B; and when by the Syphon Barometer, the letters S B are added. The number of heights given is 219.

Details of Sections.

By means of maps, and sections, and tabulated heights, I hope to make facts on this subject understood without much detail. Yet the sections will require some explanations. I shall describe them by reference to the basins in which they occur.

1. *In Basin No.* 1, *from Middletown to Holyoke, commencing at the North End.*

1. In South Hadley. (See Section No. 1, Plate I.) The section commences at Mt. Tom, in Northampton, and runs east across Connecticut river. On the east side it strikes a high gorge terrace, which has been partially worn away by the river. The line of the section is only a few rods south of the gorge between Holyoke and Tom. East of the high terrace is a small stream, that seems to have been instrumental in forming the lower terrace, which runs along the south side of the Holyoke range to Belchertown, sloping towards the Connecticut. This section might have been more instructive if extended to that place; but I have not obtained the requisite data, and those which I have used are merely barometrical.

2. No. 2 extends from Connecticut river at Willimansett, in the north part of

Chicopee, at the foot of South Hadley Falls, to the high, sandy plain which extends easterly and southerly through South Hadley, Granby, Springfield, &c. This plain is a little short of two hundred feet above the river, and two hundred and seventy-four above the ocean. It is essentially composed of sand, and I think that it sinks as we go south. East of this plain we strike beds of gravel, with irregular elevations and depressions. Above these are accumulations of coarse materials, once beaches probably, but I have not measured their height. I am sure they may be found at different altitudes, even to the top of the hills lying east of this part of the Connecticut Valley and the ocean, as high as one thousand feet.

3. In Springfield, a little north of the centre of the city, and running from the river southeasterly, so as to cross the principal terraces in that place. The third terrace is the isolated remnant of one, probably of the same height as the first one we meet in ascending from the main street eastward, on which so many delightful residences have been chosen by the citizens. The intervening space, as shown on the section, was probably worn out by Connecticut river, which might formerly have run there, when at a higher level, or at least, a part of it. The terrace marked as one hundred and thirty-six feet above the river, is that on which the United States Armory is situated. I did not actually level to the top of these two right hand terraces; but have no doubt that their height is nearly as given in the section.

4. In the extreme northern part of Long Meadow, on the road to Springfield, commencing at the river, and running southeasterly to the level of the plain on which most of Long Meadow, and the higher part of Springfield, are situated. This upper terrace extends, with some irregularity of surface, eastward about nine miles to the railroad station in Wilbraham on the Western Railroad. Northward it reaches the foot of Holyoke in South Hadley, though broken by several streams. To the south, it reaches a ridge of sandstone, commencing at Enfield Falls in Connecticut, and extending easterly to the hypogene rocks of Monson and Stafford; though there may be places where the terraces overlie the sandstone, so as to connect with the upper terrace south of Enfield, that extends as far as Glastenbury. (See Terrace No. 2, Plate III.)

5. In East Windsor, commencing at the Connecticut river, and extending easterly to the broad plain, on which stands the Theological Seminary, past which the section runs.

6. In East Hartford, from Connecticut river, at the south part of the village, to the sandy plain a little eastward. This plain I have supposed to be the same as the upper terrace of all the previous sections. If so, it slopes southerly as follows, in a distance of forty or fifty miles, viz: at South Hadley (Mt. Holyoke) it is 292 feet above the ocean; at Willimansett, 268 feet; at Springfield and Longmeadow, 200 feet; at East Windsor, 96 feet; and at East Hartford, 61 feet. But this point demands more careful examination than I have given it.

7. In Glastenbury, south part of the town. Then the valley becomes narrower, and, indeed, Rocky Hill, a trap bluff, appears on the west side of the river; and we may regard these as gorge terraces, such as form on the up-stream side of a barrier. Hence, as I find is usual, they are higher than those in the central parts

of a basin. Yet the upper terrace of this section extends almost uninterruptedly to Middle Haddam, or Chatham. It is composed of sand, with coarse gravel, or even bowlders a foot or two in diameter. It is more irregular at the top than the lower terraces, and is, in fact, a moraine terrace.

8. In Wethersfield, a little north of the village, from Connecticut river westward, the highest terrace is probably the same as Main Street, in that village. It is sandy; the lower one loam.

9. This section begins near the mouth of Farmington river, on the bank of the Connecticut, and runs southwesterly to the level of the village, which stands on the highest terrace observable in that vicinity. This is sandy, the lower one loam.

2. *Sections in the Basin from Mount Holyoke to Mettawampe.* (*Toby.*)

To the surface geology in this basin I have devoted more time and attention than in any other, because I reside in it, and have lived in it most of my days.

10. The valley of the Connecticut, in the region of Northampton and Amherst, is not less than fifteen miles wide, from the old beaches on one side to those on the other. From the north part of Northampton, through Hatfield, Hadley, and Amherst, to the middle of Pelham, I have carried a level more than eleven miles, and the section, No. 10, presents the results. It shows, first, terraces on several existing small streams, besides the Connecticut; secondly, terraces and beaches on what I regard as two ancient beds of the Connecticut, one along the west side of Amherst, and the other along its eastern side. The ridge between is mainly composed of rearranged and water-worn materials; but the surface is too irregular for terraces, and I fancy that they might have formed beaches, though terraces occur on their sides; thirdly, as we approach Pelham, we come upon the upper part of a small stream, called Fort river, which descends from the hills of Pelham, almost in the direction of the section. On both sides of this stream I found numerous terraces, some of them delta terraces, and others, lateral terraces; although not all of them are very perfect, yet lying at a convenient distance from my residence, I have given them a good deal of attention, and regard them as very instructive. I have thought that they deserved a separate map, which I have given (Plate VI, Fig. 2,) as they could not be represented on the general map. The general section I have carried along the south side of the stream, as high as the terraces exist, and then it is continued across the south branch of the stream (a mere brook), so as to cross what I regard as three beaches; one of them more than 1,000 feet above Connecticut river. The highest of the terraces, No. 9, which is 383 feet above Connecticut river, occupies a gorge having Mount Hygeia[1] on the north, and a corresponding elevation, less bold, on the south. Above this spot is a depression, or basin, above which, on the north side of the stream, occur several distinct terraces, lying against Mount Hygeia; while at a still higher level, on the north, are large banks

[1] I apply this name to a bluff 706 feet above Connecticut river, rising directly above a fine mineral spring, of the chalybeate character, in a most romantic dell.

of coarse sand, which I regard as an ancient beach, and have so marked it on the map (Plate VI, Fig. 2).

11. On the north side of the stream (Fort river) the terraces are more numerous than on the south side, and in general they do not correspond in height. I have, therefore, been obliged to give another section (No. 11), extending from Fort river, in Amherst East Village, to the sandy sea-beach above described, 546 feet above Connecticut river. The course of this section, and also that on the south side of the stream, are indicated by the succession of figures on the map. On the north side the terraces rise highest at the southeast point of Mount Hygeia, evidently because there was once a barrier at this spot, at least a partial one, which would cause the materials drifted by the current to accumulate. The depression shown by the section, still further east, was doubtless made by the action of the small stream, as it wore away the barrier. In other words, it was a pond which was gradually drained, and so the terraces were formed.

It is not easy to say whether No. 17 be a terrace or a beach. It is coarse sand and gravel, and is somewhat level-topped: yet it passes into a decided beach further south, and I have marked it as such. When the ocean stood as high as 546 feet above Connecticut river at this spot, it must have produced a small bay opening to the north; Mount Hygeia forming the right hand side and Pelham Hill the left. Nearly 400 feet higher, we find another beach, which, on the general map, I have represented as extending through Shutesbury, several miles to the north. It can be traced a great distance, and probably might be found extending into New Hampshire. In Shutesbury it is very distinct, and more sandy than in Pelham, where, at its highest line, the rolled fragments are sometimes a foot in diameter. By carrying a level from Packard's Hill, in New Salem, the height of which has been accurately determined in the Trigonometrical Survey of Massachusetts, I found the most distinct beach in Shutesbury to be 1082 feet above Connecticut river. This corresponds nearly to a third beach on the east side of Pelham Hill, half a mile south of the Congregational Meeting-house, on the road to Enfield, which is 1049 feet above Connecticut river. Between these two highest beaches in Pelham, most of the surface is covered by ordinary drift, with rocks in places (gneiss) occasionally shooting through. Drift, also, appears between the lowest and the second beaches.

This section across the Connecticut valley I am convinced gives us a good idea of the character of a large part of the valleys of New England and New York, and perhaps of the whole country, with the exception of drift. Wherever I have travelled, since my attention was turned to the subject, I find terraces in the lower part of the valleys, and similar though usually coarser materials arranged beachwise, on the flanks of the mountains and hills, especially where spurs of the ridges form spots that might once have been bays, in which sand and gravel would naturally be accumulated on the shores of a lake, or the ocean, by winds and waves. There are scarcely any mountains of New England so high that this work has not reached their summits. But further on I shall have occasion to point out other particular examples.

The section of terraces on the north side of Fort river, passing most of the way

through thick woods, I used barometers for getting their heights, except Nos. 11, 12, 13, and 14, which were obtained by levellings. Along this route the rock often projects through the terraces, and shows decided evidence of powerful erosion by aqueous agency, some hundreds of feet above the present stream.

12. This section is in Whately, on the west bank of Connecticut river, and extends only to the third terrace above the river. Had I followed up the side of the mountain in the west part of the town, no doubt I should have found beaches, and most likely one or two other terraces above No. 3. Indeed I know of one terrace, say 100 feet higher than No. 3, about two miles south of the line followed by No. 12, and I shall in the sequel point out a very high beach in the north part of Whately. The principal uses of this section, thus imperfect, are to show that the lowest terrace along the Connecticut is sometimes quite high (32 feet here), and that the height of the broadest terrace in the Connecticut valley, which is No. 3, is less than it is nearer to the gorges; a fact which shows the influence of those gorges in the accumulation of the materials of the terraces.

As already stated, there are two branches to this second basin, one extending north through Deerfield and Greenfield, and the other south through East Hampton, Westfield, Southwick, &c., nearly if not quite to Long Island Sound. These branches are separated from Connecticut river by an almost continuous ridge of trap and sandstone, as may be seen on the large accompanying map of the surface geology of the Connecticut valley. This ridge is breached in Deerfield by Deerfield river, in Westfield by Agawam river, and in Simsbury by Farmington river. On the two first of these rivers are two remarkable sub-basins, sunk some 80 or 100 feet below the general level of the valley, and exhibiting on their margins fine examples of terraces. As these cannot be well shown upon Plate III, I have devoted separate ones, but on a larger scale, to their exhibition. (See Plates IV and VII.) They both extend a considerable distance along the rivers, and show the surface geology, especially the terraces and old river beds.

The Deerfield Basin.

13. Where Deerfield river emerges from its long *Ghor*, between Shelburne and Conway, into the Connecticut valley, it has formed several terraces; a section of which No. 13 exhibits; though on the south side of the river I have failed to measure two small terraces. But on the north side of the stream a tongue of four or five terraces has been thrown forward, perhaps a mile long, forming a ridge a little over a hundred feet high, with regular terraces on its south side. The stream here descends rapidly, and so do the terraces slope in the same direction, although I did not measure the rate of descent. It is so obvious to the eye that I thought a measurement hardly necessary, especially as I find the same fact almost everywhere upon lateral terraces. They always have as great a slope as the stream on which they occur, and sometimes greater.

Until I discovered the tongue of terraces above described, I was of opinion that the basin of Deerfield was once occupied by terrace materials to the height of No. 3 (yellow) on Map No. 1, Plate III, which is the usual level of the Connecticut valley

in that region, and is upon an average 173 feet above Deerfield river. This amount of sand and gravel (as I estimate it, 135,000 cubic yards) I supposed had been cut away by Deerfield river, and sent forward into the Connecticut. But I can hardly see why this ridge of terraces should in that case have been left. Yet some other facts seem to indicate strongly that most of the whole basin has been thus excavated; and upon the whole, I think this tongue of terraces has been formed by the river after it had excavated the basin, and sent its contents down Connecticut river.

The tongue of terraces above described was undoubtedly at first a delta terrace, though formed by the rapid stream as it issued from the mountains into the estuary, which is now the Connecticut valley. At present, the ice-floods in that stream, and at this very spot, exert an amazing power of erosion. In early times, such floods must have crowded along great masses of crushed and rounded materials, and piled them up along the margin just as lateral moraines are produced by glaciers. As the bed of the stream sunk, and also the waters of the estuary, successive terraces would be formed, looking like so many moraines, although of finer materials than the moraines of glaciers, and sorted too.

14. This section extends across the Deerfield basin, though not exactly on a right line. The eastern part starts at Deerfield river, just south of the village, and the western part from the meadows, a little north of the village. Yet there is no error in representing them as connected, since at their starting points they are nearly on the same level, differing in height only as the banks of the river differ. The terraces are very distinct till we reach the third, over which the railroad passes, on the east side of the valley. Above the third, the top of the deposits is only imperfectly level, and they may be regarded perhaps as beaches; for I am confident that such beaches may be traced all along the flanks of the Connecticut valley, at about the same height. But I have not measured them, save in a few places, as they did not attract my attention when I measured the terraces. The three lowest terraces on both sides of Deerfield river, were measured by levelling; the two highest, by the syphon and aneroid barometers. Yet the latter, on the west side of the river, have not been measured at all. As I saw them from the east side, they appeared to be at about the same height as those on the east side; still I know well how difficult it is to judge accurately in such cases by the eye alone, and actual measurement might show a considerable discrepancy in the heights. Hence, I have added an interrogation point to the heights on the west side of the river.

15. This section, of no great importance, shows the terraces at the north end of Deerfield meadows, to the top of Pettee's Plain, which lies southwest of the village of Greenfield, and corresponds to the general level of the Connecticut valley. The meadows, or lowest terrace, are here worn away, and the lowest terrace remaining is mostly clay; the upper one sand. The river would encroach still further upon this hill, had it not struck a ledge of red sandstone, which will at least retard its lateral erosion.

16. Pine Hill is an insulated eminence, apparently composed of two terraces, in the northern part of Deerfield meadows. These terraces do not correspond in height, as far as I can see, with any on the margin of the basin; yet they must have been once continuous, as I know of no instance where terraces have been formed

so perfect upon a small hill. This fact goes strongly to show that at least a large part of the Deerfield basin was once filled with terrace materials, which the river has subsequently worn away, and the reason why those on Pine Hill remain, I find to be that they rest on a protuberant mass of red sandstone. On the west side of the hill, as shown in the section, is an ancient bed of Deerfield river (crossed twice by the section), which was prevented from making any further lateral encroachments by the underlying rock. I shall have more to say hereafter concerning the ancient beds of Deerfield river, shown in such numbers upon Map No. 2 (Plate IV).

A few other terraces on Deerfield river, out of the Connecticut valley, will be noticed further on.

The Westfield Basin.

17. The major axis of the Deerfield basin lies north and south; that of the Westfield basin nearly east and west. The present section starts from Agawam river, near the east end of the basin, on the north side, and runs northerly. The height of the four lower terraces was obtained by levelling; that of the highest by estimation. All of them, except the lowest, which is loam, are sandy. The most elevated brings us to the general level of the Connecticut valley, though it is for the most part lower towards the east side, and not a little irregular on its top.

18. This section was but imperfectly measured, and only with the arenoid barometer; which, although very valuable where an error of twenty or thirty feet is not of much consequence, does not answer well for such small elevations as our river terraces. By looking at Map No. 6, it will be seen that between Westfield river and Little river, a tongue of terraces extends easterly from Middle Tekoa Mountain, almost to the village of Westfield. In one place on the north side of this tongue, perhaps a mile west of the village, I noticed five terraces, reckoning that on which the village stands as the lowest, although generally the highest terrace around Westfield is reached by three steps from the river. Commencing on the high sandy plain north of Westfield basin, I have carried this section southwesterly across these five terraces and over Little river to the plain of nearly equal height on its south bank; in other words, across the entire basin. I think the barometer has made the central terraces considerably too high. But the section will give an idea of this interesting valley. The materials of which all these terraces are formed are clay, sand, and gravel, though the red sandstone shows itself occasionally near the river.

19. On this section I have attempted to give an idea of what I suppose to be the remnants of gorge terraces, where Westfield river issues through the deep gorge between Tekoa and Middle Tekoa. The height (measured by the Aneroid), is very great for a stream of no larger size. Near the river on the same section are shown two other narrow terraces, produced at a vastly later period. On both sides of the river the mica slate ledges show themselves frequently as we ascend the mountains.

20. This section commences on the east side of Westfield river, opposite the station house of the Western Railroad, in Russell, and crosses the river, passing westerly through the flourishing village which has lately sprung up there. Its

western extremity is very near the place where an old river bed, about a mile long, unites with the present bed. I do not feel much confidence in the accuracy of the heights, since they were taken by the aneroid barometer. For the view of the terraces on which this village stands, accompanying this paper (Plate IX, Fig. 2), I am indebted to Mr. Franklin P. Chapin, who took it with his pentagraphic delineator from the east side of the river.

21. This section extends from the present bed of Westfield river over the hill on its west bank, and across the old river bed referred to in the last paragraph. The heights were obtained by the aneroid barometer; and, therefore, are liable to some uncertainty.

Many other terraces are shown along Westfield river on Plate VII, with three old river beds to be described in my paper on erosions. The heights of the terraces I have not measured, and therefore do not give sections of them.

3. *In the Basin extending from Mettawampe to the Mouth of Miller's River.*

22. This basin, though small, has many terraces, but none of them seem to me of special interest. I have measured only one section in it, and not the highest terrace upon that; as it lies at a distance from those which were measured. I commenced on the narrow alluvial plat just above Turner's Falls, on the Montague shore, and ascended the sandy hill that lies southeasterly. This was reached as the third terrace; and, except along its eastern margin, it constitutes the general surface of the basin. At its southern part, in the south part of Montague, I judge the surface to be higher than on the section, as is usually the case near gorges.

4. *Sections in the Basin extending from the Mouth of Miller's River to Brattleborough.*

I ought to repeat here, and make more general, a remark elsewhere made, that the upper terraces usually extend more or less from one basin into another; that is, these higher terraces were formed when the waters extended from one basin into another, and what now seem to have been barriers, were then only narrower places in the estuary. On the east side of the river, in this case, terrace No. 4, and perhaps No. 3, on Map No. 1, Plate III, were continued into Northfield from the basin next south.

23. This is in Northfield, two miles south of the village, running eastward from Connecticut river. The fourth terrace, or beach more properly, is irregular on its top, and was not measured.

24. This runs from the same river eastward in the north part of Northfield, only a short distance south of the State line.

25. At the mouth of Ashuelot river, in Hinsdale, the terraces are numerous and instructive. This river is a small but rapid stream, and where it debouches from the hills into the Connecticut valley, it has brought forward a large mass of terrace materials, mainly of gravel, which originally constituted a delta terrace; that is, the stream threw forward these materials into the lake, or estuary, and formed a bank along its mouth. But as the waters drained off, so as to bring this

bank above them, the Ashuelot cut through them, and formed lateral terraces along its margin. On the northern side of the stream, at its mouth, a rocky hill extends nearly or quite to the Connecticut, which is thereby forced at this spot to make a curve westward. The section No. 25 passes across the Ashuelot near its mouth, directly through the village, northwesterly over the hill, and then descends towards the Connecticut; so that all the terraces on it to the right of this hill belong to the Ashuelot; while those to the left belong to the Connecticut. The difference in their height and size on the two rivers affords a good illustration of the fact that the larger the river the higher the terraces. The character of the materials, too, illustrates another fact, viz., that they are coarser on small and rapid streams than on larger and more tranquil ones. Excepting the lowest, which are narrow, the terraces on the Ashuelot are all gravel, mixed with sand, and often the fragments are quite large; while on the Connecticut are no pebbles of consequence, but sand underlaid by a thick bed of clay. A third circumstance deserves notice: On the Ashuelot the terraces have a rapid slope towards its mouth, corresponding to that of the river, which here falls so much as to afford a good site for manufactories; whereas, on the Connecticut, the eye cannot perceive that the terraces are not strictly horizontal. Indeed, they probably decline but little from Brattleborough to this place, and the two higher ones are nearly continuous between the two places. The higher terrace along the Connecticut, not measured, is sandy and irregular, and more properly deserves the name of a beach.

26. This section (Plate II) is on the west side of Connecticut river, in the north part of Vernon, and differs but little from that already described on the same river in Hinsdale. The height of the fourth terrace, however, is greater; but the spot is not a great distance south of the gorge in the river at Brattleborough, and hence we should expect a greater amount of terrace materials.

5. *In the narrow Basin from Brattleborough to Bellows Falls.*

So narrow is the valley between Brattleborough and Westminster, that it deserves the name of a defile rather than a basin. And yet terraces are found nearly the whole distance, though usually quite narrow. Opposite Brattleborough, on the east side of Connecticut river, West River Mountain rises very precipitously to the height, above the river, of 1050 feet, as I ascertained by a not very accurate mode of observation. On the west side of the river, the hills rise more gradually, yet the rocks press closely upon the bank. Within a distance of not over half a mile, two tributary streams empty into the Connecticut; the most northerly called West river, of considerable size; and the one at the south end of the village, small, and called Whetstone brook. Such streams, debouching in such a spot, and at right angles to the course of the Connecticut, are sure to produce numerous terraces. So numerous are they, and so complicated, that I judge it necessary to devote a map to them alone, so far as I have traced them out (see Plate V;) for I have not obtained quite all the facts in respect to the sections that would have been desirable, yet I have enough to be very instructive as to river terraces.

27. This section (Plate II) commences on the west bank of the Connecticut and

the south bank of Whetstone brook, and runs southwesterly to the top of the elevated sandy plain that passes into the Basin No. 4, just considered. (See the line of the section on Plate V.) The terraces appear to be the joint result of Whetstone brook and of Connecticut river. They are, therefore, more numerous than is usual on the Connecticut, and less so than on this same Whetstone brook, a mile from its mouth, as the next section will show.

The Connecticut valley was probably occupied originally by terrace materials as high as the uppermost of the above terraces on this section, and when the waters gradually subsided, both the Connecticut and Whetstone brook formed channels through these materials, and produced the successive terraces. Why terraces, rather than a continuous slope, were formed, I shall endeavor to show in another place.

28. This is a quite instructive section, commencing on the south bank of West river at its point of junction with the Connecticut, then extending southwesterly across the village of Brattleborough to the high bank of Whetstone brook, a little west of the village, opposite Burge's factories; thence across the brook, and up the opposite bank, so as to cross the successive terraces, ten in number. The upper one was not measured, on account of the rain. Nor did I ascertain the height of the brook, where the section crosses it, above Connecticut river.

It will be seen that No. 5, on the left hand part of this section, consists in part of an insulated hillock, crossed a little north of the village; and in the main part of a broad terrace, on which stands the upper and northwest portion of the village. This terrace, as I found by levelling, slopes towards Connecticut river at the rate of 20 feet in 50 rods. Possibly this might have been in part the result of rains for a long period, bringing down from the hill by which the terrace is bounded, deposits of sand. More probably the terrace was formed by the conjoint action of West river and Whetstone brook as a delta terrace, and that its slope was produced by the rapidity of the currents.

All these terraces are underlaid by argillaceous slate, which shows itself all along the banks of the streams. It is doubtless this solid rock that has determined the present channels of the tributaries to the Connecticut, and caused them to enter that river nearly at right angles. The mere sand and loam of the terraces would soon be washed away in time of freshets, were it not for this rocky foundation.

In this section we see a good exemplification of the statement made on a preceding page, that the smaller the stream the smaller are the terraces, and often more numerous too. Here we have ten on Whetstone brook, and nine on West river, yet they do not rise so high as the fourth, on the Connecticut, in Vernon.

Had I explored the hills by which the valley at Brattleborough is bounded on the west, I might have found beaches, or imperfect terraces, at a much higher level. But when I examined that region my attention had not been called, as it was subsequently, to the subject of beaches. The same remark will apply to nearly all the terraces of which I have given sections on the Connecticut.

I regret that I did not measure a section across Whetstone brook through the middle of the village of Brattleborough, along the track marked by the figures 1, 2, 2, 3, 4, on Plate V. Here it would seem are fewer terraces than at the mouth

of the stream. Possibly more careful examination might have detected others, and probably also the original surface has been here somewhat altered by the grading of the streets.

29. This section commences with the highest distinct terrace in Westminster, a little south of the village (which stands upon the second terrace, reckoning upwards), and crosses Connecticut river into Walpole. But unfortunately I was unable to measure the terraces on the east side of the river, and have marked them only as they appeared from the west side. They are very distinct on both sides, and perhaps they correspond in height, though I usually found in such cases, that actual measurement showed considerable difference in elevation where the eye could discern none.

30. At the upper end of the basin under consideration, the terraces are numerous and distinct, just below, as well as above Bellows Falls in the next basin. No. 30 crosses Connecticut river at the mouth of Saxon's river on the west side, and of Cold river on the east side. Of course the terraces are compounded of the effects of the three rivers. It will be seen that there is no correspondence in their height on opposite sides of Connecticut river, except that the upper terrace very probably once filled the valley; for the difference in height between the opposite terraces (17 feet) is not greater than we might expect on the supposition that the materials were drifted into a former lake, or estuary, by the adjacent streams. These materials are, for the most part, coarse sand, sometimes mixed with gravel. On the east side ledges of rocks appear on the slope of the third terrace.

As an illustration of this paper, I have given a sketch (taken by Mrs. Hitchcock) of the general aspect of the terraces of the above section, as they appear about a mile south of where it crosses Connecticut river, on the road to Walpole. (See Plate IX, Fig. 1.) The view from this spot of the gorge with its terraces, and of some of the principal buildings in the romantic village of Bellows Falls, is very fine, and deserves the attention of the artist for its scenographic beauties. My object in giving its outlines was to exhibit the terraces as a good example of the very artificial appearance of many spots along the rivers of New England. Certainly it does seem, as we look at these terraces, as if they were the work of man.

31. On the preceding section, on the west side of Connecticut river, I have represented two *glacis terraces*. On No. 31 I have shown them on a large scale, and laid them down accurately, so as to give a good idea of this kind of terrace. It will be seen that they constitute merely undulating portions of the lowest terrace, and perhaps ought not to be reckoned as distinct terraces. Yet they are sometimes of considerable height, and certainly deserve notice, because they show us one of the modes in which water accumulates terrace materials. How they are formed I will consider in another place. But there are certain laws concerned in their production. Thus, the depression between them always corresponds in its longest direction with the course of the current that produced them. One side, also, and I believe always that next the stream, is steeper than the other.

In almost all extensive meadows this sort of terraces may be seen more or less distinct. Excellent examples occur in Hatfield and Hadley, not merely in the meadows, but they are seen in crossing the villages, from street to street, in an

east and west direction, or at right angles to the course of the stream that made the deposits.

It was from such examples as this section exhibits that I first got the type of a glacis terrace; but in passing subsequently through some of the higher valleys of the Alps, I sometimes observed the terrace materials arranged so as to form one continuous slope from the rocky side of the valley to the stream. I noticed this most distinctly on the Eau Noire, in the pass of Tête Noire. Here the materials were quite coarse, the fragments often large enough to be called boulders, though I fancy most geologists would be puzzled to say just how large a *pebble* may be, or how small a *boulder*. The same sort of terrace I saw in other places in the Alps, and I have observed them in the mountainous parts of our own country, though but seldom, and they were imperfect. They perhaps furnish a better type for the glacis terrace than that already described. If, however, we regard the gentle slope on one side as a characteristic of this terrace, then both the above descriptions of terrace will belong to it.

6. *In the Basins extending from Bellows Falls to Wells River.*

The mountains at Bellows Falls crowd closer upon the river than at any place south of this spot, except perhaps at Holyoke and Tom. Kilburn Peak, on the east bank, rises almost perpendicularly, over 800 feet. On the west side, as at Brattleborough, the mountains recede further, and have an escarpment less steep; yet the rocks show themselves almost everywhere in the gorge, and form a ridge which produces the falls. All the circumstances here are favorable to the formation of terraces. Sections 30 and 31 are only a mile and a half south of the village of Bellows Falls, and the highest terraces extend through the village into the sixth basin. So remarkably are they grouped together here, that a distinct and separate map seemed indispensable. (Plate VI., No. 1.)

32. This section crosses Connecticut river directly through the village of Bellows Falls and a few rods above the principal cataract. The heights are given from the foot of the falls. The depression on the left was evidently once occupied by the river when at a higher level. I regret that I was not able to measure all the terraces—none, indeed, on the east side of the river; but I am not aware that they are peculiarly instructive.

It was my intention for a long time to continue to get the heights of terraces through the whole course of Connecticut river, at least as frequently as they are given above. But I began to be convinced that I had already measured enough for all important purposes in relation to river terraces. The phenomena of beaches arrested my attention more and more, and it seemed a very important point to ascertain how high they could be found upon the sides of our mountains. To this problem I addressed myself, both in this country and in Europe, and shall briefly give the results. But something more needs first to be said concerning the terraces.

As to those above Bellows Falls on Connecticut river, I have but little to state; for although I have passed over the region several times, it has been rapidly, and I can only say that at least three terraces may be traced nearly all the way to

Wells river. Sometimes I noticed four, or even more. But with one or two exceptions, I have marked only three on the map, and I fear that I have but very inaccurately represented the position and relative width of these. Neither do I suppose that the basins above Charleston, are accurately laid down. In some places, as at Wethersfield, and above Haverhill, the terraces are very perfect and beautiful.

33. My son, Charles Henry Hitchcock, measured this section at White river junction, with the aneroid barometer, and I have thought it worthy to be added in this place, especially as I know from my own observations that its outlines are correct. It commences at Connecticut river, and passes west, near the railroad station. The old river bed, on its west part, was probably formerly occupied by White river, which entered the Connecticut, a little below its present junction. I am not certain, however, that this was the case.

Terraces chosen as the Sites of Towns.

It is a curious fact that the most attractive villages in the valley of Connecticut river, owe their chief beauty to being placed upon terraces. Among these towns we may mention Wethersfield, Ct.; Hartford, East Hartford, Windsor, East Windsor, Springfield, West Springfield, Northampton, Hatfield, Deerfield, Greenfield, Northfield, Hinsdale, Brattleborough, Westminster, Walpole, Bellows Falls, Charleston, Wethersfield, Vt.; Windsor, Hanover, Oxford, Haverhill, and Newbury. Probably but few of the inhabitants have ever thought as to what they are indebted for the beauty of their towns.

Terraces and Beaches out of the Connecticut Valley, but in New England or New York.

I have already described the terraces on Westfield river, among the mountains west of the Connecticut valley. But they occur on almost all the rivers of New England, and I have not attempted the Herculean task of measuring or even mapping but a small part of those which I have visited since engaged in these researches. After finding the features of them to be essentially alike on all rivers, I became convinced that the measurement of great numbers was not important. I will only refer to those on a few rivers, which I have observed with special interest, as well as to beaches, which I have noticed on the adjoining hills.

Merrimack river abounds with terraces, the most perfect of which are in New Hampshire. They give great beauty to many of the towns along that river. From the south line of the State to Franklin I have traced them, and with some interruptions, two or three of moderate height may be seen on one side or the other, or both sides, nearly the whole distance, as I have shown without much accuracy on Plate III. Near the mouth of the river I found terraces, but could rarely find more than one well defined, and so have I represented them on the same map.

Plum Island, stretching along south of the mouth of the Merrimack, is a good

example of a modern beach. (See Plate III.) Some other features of the surface geology of that region I have delineated, and shall notice further on.

A slight examination led me to the conclusion that the terraces are of unusual interest upon Ammonoosuck river, which comes from the White Mountains and empties into the Connecticut.

I have followed up the Waterquechee river in Vermont to a considerable distance, and find some interesting terraces a little below the village of Quechee, where is a wild gorge. Above this not less than seven terraces occur on the southwest side of the stream, and four on the opposite side, as I have indicated simply by lines upon Plate III., connected with my paper on the marks of drift and glaciers.

On the same map I have sketched most of the terraces on Deerfield river above Shelburne Falls, where the Ghor terminates. Generally, we have along this stream only two terraces, as represented, though sometimes more exist, as section 34 shows, to be described below. But where small streams enter Deerfield river, I have noticed fine examples of the Delta Terrace, and several of these are marked upon the map, and will be more particularly described further on.

I now proceed to describe Section No. 34, just referred to, as well as several others, mostly of beaches out of the Connecticut valley.

34. Beyond the barrier across Deerfield river a little west of Shelburne Falls, commences a rather broad valley, which must have been once a lake, extending perhaps fifteen miles, to the foot of Hoosac mountain. Here, as we might expect, we find good examples of terraces. I have measured, however, only a single series, lying on the south side of Deerfield river, and at the mouth of a small tributary coming in from the south through Buckland. It will be seen from the section, No. 34, that the terraces are all of them low. They seem to be the result of the joint action of both rivers.

35. In the southeast part of Heath is a mountain, to which the Indian name of *Pocumtuck* was formally given in 1855, by the Senior Class in Amherst College who graduated in 1856. It was used as a station in the trigonometric survey of Massachusetts, and consequently its height above tidewater is known to be 1888 feet. From this point I levelled northwesterly about two miles, till I struck a deposit of water-worn sand and gravel, of limited extent, but which I must regard as an ancient beach; for I know not how else to explain the occurrence of comminuted and sorted materials in a spot so elevated and open to the surrounding country. The section will give an idea of its position.

36. The summit-level of the Western Railroad, in Washington, is 1456 feet above the ocean; the cut in the rock being 60 feet. On all sides of this cut I find deposits of sand and sometimes gravel, at least to the height of 134 feet above the original rock. This would give 1590 feet above the ocean as the highest mark of distinct sea action at this place, although very probably similar deposits can be found in the vicinity at a higher level. But I am a little doubtful as to some of these banks of sand; for the rock here is a variety of gneiss easily disintegrated, and the result of the disintegration is coarse sand. I cannot thus explain, however, the thicker deposits, certainly not those with pebbles, and these are seen nearly at the height above named.

This spot was doubtless one of the lowest, if not the lowest, pass through the dividing ridge between the Hudson and Connecticut rivers, and therefore we should expect marks of sea action here, if the ocean once stood above the mountains of New England.

37. French's Hill, in Peru, on Hoosac Mountain, is one of the highest peaks in Massachusetts, and as its height was ascertained in the trigonometric survey, I visited the spot in the hope of finding beaches or terraces in the vicinity, whose height, also, above the ocean, could be easily determined. The section No. 37 exhibits the result. By carrying a level downward from the top of French's Hill we strike what I conceive to be an ancient beach, 217 feet below the summit, or 2022 feet above the ocean. It is level like a terrace, but the materials are not very thoroughly rounded, like those of the lower beaches and terraces; yet they are more worn than drift usually is, and I can impute the level top of the deposit to water only.

Passing eastward from this beach, we cross a brook, which rises in a pond, and then go over a hill of considerable height. In descending it easterly, I fancied the existence of another beach; but, going onward, nearly three miles from French's Hill, and descending about 470 feet, we reach a small stream, where are at least three terraces, made up of coarse materials, sand, gravel, and bowlders, the highest on the west bank being 85 feet above the stream, and 1852 feet above the ocean. This is the highest river terrace I have yet met with in New England; but I see no reason why they may not be found at a higher level in some of our mountains, since, as I conceive, they are mainly the result of the action of the stream itself. In this instance, however, it is rather difficult to imagine the former existence of any barrier high enough to shut in the water, so that it would overflow these terraces: so that probably the sinking of the waters of the ocean may have had an important influence on their production. On the east side of the stream are three terraces of about a corresponding height, but I did not measure them.

Proceeding eastward from this elevated region, I met with other deposits at a lower level, more obviously once constituting the shores of an ocean; but not then having barometers with me, I could not measure their height.

In going westward, also, from Peru, or any other culminating point of Hoosac Mountain, into the valleys of Berkshire County, we meet with many examples of comminuted and rearranged drift, in the form of beaches, and in the valleys of terraces. But I have not measured the height of these, save a single example on the Western Railroad in Dalton, which I find by the aneroid barometer to be 1228 feet above Hudson river.

In the west part of Whately, on the ridge between that town and Conway, I found a distinct beach of sand and gravel, which by the aneroid and siphon barometers I ascertained to be 697 feet above Connecticut river, and 802 feet above the ocean. In the northwest part of Conway, called Shirkshire, I found another, of coarse gravel and sand, 935 feet above the river, and 1040 above the ocean. Two miles further west, in Ashfield, is another, mostly of sand, 976 feet above Connecticut river, and 1081 above the ocean. A mile further north, an imperfect beach shows itself, 1216 feet above the river, and 1321 above the ocean.

Still further northwest, on the opposite side of the ridge, is another sandy beach, nearly as high, but I did not measure its elevation.

In all the above cases, and, indeed, wherever I have discovered the most distinct beaches, they occupy such a position among the hills, that if the country were covered by water a few feet above the beaches, they would become inlets or harbors, and I fancy that if our present harbors, either along the ocean, or the shores of our larger lakes, were to be left by the waters, the surface would be no imperfect counterpart to these ancient beaches. Indeed, when standing on these beaches, and looking in the direction which must have been *seaward*, if my suppositions are correct, I have often felt that it required no great stretch of imagination to see the ancient waves rolling in upon the beach, and silting up the harbor.

Upon Map No. 1, I have marked beaches at Franconia Notch and the White Mountain Notch, which are two passes through that gigantic range of mountains. In those passes, a little west from their narrowest part, we find accumulations of water-worn detritus, stratified and laminated, which I doubt not were left there by the breakers of an ancient ocean. At least it is certain that no existing streams could have formed them, and yet water must have been concerned in their production. By my aneroid barometer, I found the highest point in the road, which passes westerly from the Franconia Notch house, to be 2665 feet above the ocean, and 2259 above Connecticut river. This is not so distinct a beach, however, as is shown at the height of 2449 feet above the ocean. Gibbs' hotel, at the White Mountain Notch, which occupies the top of a beach, in my opinion, is 2018 feet above the ocean by a mean of the two barometers, and 1612 above Connecticut river. But I fear this measurement may vary somewhat from the truth.

38. This is a very imperfect section, from the mouth of Connecticut river to that of the Thames, at New London, or a little north of the city. I had no intention of making such a section when I crossed that district in the road nearest to the coast, not far from the route of the New London and New Haven railroad. But having taken a few barometrical observations, and finding the two barometers to agree unusually well, I thought it best to put down the different terraces and beaches which I observed, although I have given the heights of only a few; and probably some terraces, at least, are omitted. Perhaps all should be called beaches, as they lie open entirely to the ocean. But the rivers seem to me to have had more to do in their formation than the ocean. The beach marked 17 feet high, on the west bank of Connecticut river, seems to me of the same height, as the very distinct one, commencing on both sides of the Thames, and extending as far as Norwich. This, however, is in fact a terrace, and at New London there is a rocky barrier, which doubtless had something to do with its formation. I regret that I could not spend a longer time along this section, and make more measurements. At the time, I thought the terraces and beaches too low to be measured accurately by the barometer, and I had no level with me. I think it would be instructive to run such a section along much of the coast of New England; yet I think the one given is an epitome of what we should find in the whole distance.

39. In passing from Schenectady to Albany and Springfield, I took observations with the aneroid barometer at certain places, which I had often observed to be

the tops of terraces and beaches, and have given the result on this section, which commences at the highest part of the sandy plain lying between Albany and Schenectady, and, following the railroad, terminates at the highest point on the road of the Hoosac range. The horizontal scale is so small compared with the vertical, that the section is very much distorted, and gives but a poor idea of the country passed over. On the east side of the Hudson, after rising to the third broad terrace, the ascent is gradual most of the way to the State line between New York and Massachusetts, a distance of 38 miles. Between that point and Pittsfield, eleven miles, the surface is chiefly covered with unmodified drift. Thence eight miles to Hinsdale, the drift is frequently covered by re-arranged drift, which I suppose to have been modified by the ocean, beating against the side of Hoosac Mountain. The same is true of the remaining five miles, which brings us to Washington, on the summit level, and, as already explained, I have regarded the sea action there as extending upwards above the railroad 200 feet.

Though at each of the railroad stations where I took observations, I have represented a distinct beach on the section, it must not be supposed that such is the fact at those places, while between them no beaches exist. I mean only to indicate that beach materials exist at those places, but exactly how many distinct beaches exist along the route, I am unable to say. That the whole of this inclined plane once constituted the shore of a retiring ocean, I cannot doubt; but how many pauses there might have been in the vertical movement, so as to form marked beaches, is a point I have not determined.

At some of the stations of medium height, say at Chatham and East Chatham, I noticed those irregular elevations and depressions of sand and gravel, which I have already described as occurring among the highest of the perfect terraces, and below the most distinct beaches. From this fact we must infer that at that particular level of the waters some peculiar action must have taken place, necessary to produce these modified effects. I refer to those accumulations which I have denominated Moraine Terraces.

40. This section was taken by the aneroid barometer, on the west side of Genesee river, in Mount Morris, which lies at the lower end of that remarkable gorge cut by the river from Portage to that place. There is nothing very instructive in the section. We see, however, that the terraces here are of great height, and they are, also, in general quite broad. An enormous quantity of detrital matter has in past ages been brought into the Genesee valley, and there are some quite instructive facts in relation to former changes of river beds. But this subject I shall reserve for my paper on Erosions.

Terraces on Rivers and Lakes at the West in our Country.

I have not had much opportunity to examine our western rivers and lakes with reference to the surface geology of their banks. The Ohio did not seem to me remarkable for its terraces, nor did the Great Kanawha. On them both we meet occasionally with two terraces, sometimes three. The horizontal position of the sandstone and limestone strata in the Western States, exposes one to error in this

matter, by mistaking a terrace of rock for one of sand or gravel. There is no danger of such a mistake in New England.

The terraces and beaches around a considerable part of Lake Superior have been described with great scientific accuracy by Professor Agassiz, in his work on Lake Superior, and by Messrs. Desor and Whittlesey in the Reports of Foster and Whitney on the Lake Superior Land District. The latter gentlemen have, also, included a considerable part of the shores of Lake Michigan.

From the details given by these gentlemen, I judge that surface geology in the regions of these great lakes corresponds essentially to that of New England. Though the different forms assumed by the materials may in their writings often be given under names different from those I have used in this paper, the things described appear to be identical. There is a coarse drift underlying all the other forms of detritus, and above this lie deposits of clay, sand, and loam, overspread in many places and mingled with blocks of various sizes, generally more or less rounded. M. Desor considers the lowest deposit of the clay some 60 feet thick, and those of the sand and gravel above, some 360 feet thick, to belong to the drift, because mixed with, and covered over, with boulders. He divides all the superficial deposits into three parts. 1. Drift proper, with the above four subdivisions. 2. Terraces belonging to a later epoch—a part of the terraces he includes in the drift. 3. Alluvial deposits, embracing all those forms of detritus that have accumulated since the continent began to rise from the ocean, such as beaches, terraces, nooks, belts, bars, marshes, flats, and subaqueous ridges.

As to the number of terraces, M. Desor speaks of as many as seven in some places, and Professor Agassiz says that "six, ten, even fifteen, may be distinguished on one spot." The number, all agree, varies very much in different parts of the same lake. Professor Agassiz thinks that "these various terraces mark the successive paroxysms or periods of re-elevation" of the shores of the lake. Desor adopts the same view, certainly so far as to say that the terraces indicate pauses in the vertical movement, which, however, he would make general over the continent; for he finds the drift deposit at the top of the highest parts of the country around these lakes, not less than 1000 feet above their present level.

Now it will be seen that while I agree with these gentlemen in regard to the essential facts of surface geology, we differ as to the mode of stating them, and somewhat in the theory of the whole subject. We all agree in supposing the phenomena to require vertical movements in our continent, or its submergence and emergence since the tertiary epoch. But while they suppose that there were pauses in the vertical movement, long enough to form the different terraces, I have been led to suppose that most of them, certainly river terraces, must have been formed without such pauses, and simply by uninterrupted emergence or drainage of the country. We agree as to the occurrence of a deposit of coarse drift at the bottom of the series; but while they regard the superimposed clay and sand as true drift, I suppose them modified drift, and produced almost entirely by water, save that floating icebergs have dropped the large boulders. They, certainly M. Desor, suppose the drift period to have terminated when the continent began to emerge, and the alluvial to have then commenced; but I regard drift proper as the result of

several agencies—icebergs, glaciers, landslips, and waves of translation—which, indeed, operated most powerfully in the earliest periods, but have ever since continued to act and are still acting. And so of alluvial agencies: we find evidence of their operation from the close of the tertiary period; nay, much further back; but they have gone on increasing in power to this time. Thus the drift and alluvial agencies have had *a parallel operation* from the first, and hence the difficulty of separating drift and alluvium, and the propriety of regarding the whole as one prolonged period, with synchronous deposits. These views will be more fully developed in the subsequent parts of this paper, and I mention them now to avoid misapprehension.

In Professor Owen's Report on the Geology of Wisconsin, Iowa, &c., many interesting facts in surface geology are mentioned; such as terraces and old river beds. On the St. Peter's river he describes two terraces above the meadows, one 130 feet, and the other 230 feet high—the latter of coarse materials. On Red river, according to Captain Marcy (*Report*, p. 35), are three, the lowest from 2 to 6 feet above the stream; the second from 10 to 20 feet; and the third, from 50 to 100 feet; forming the most elevated bluffs along the river.

On the River Jordan, in Palestine. Dr. Anderson, geologist to the exploring expedition sent out by the United States Government to the Dead Sea, has given us an account of the terraces in the valley of the Jordan, a river so remarkable for its tortuosities and rapid descent. He says: "There are almost everywhere in the Jordan valley, distinct traces of two independent terraces. The upper terrace extends to the basis of the rocky barriers of the Ghor, both on the east side and the west, and appears to have been due to a geological condition long preceding the existence of the actual river, yet subsequent to the removal of the material which once occupied the space between the two opposing cliffs." We understand him to mean that there are two terraces besides the meadows, or lower bank of the river; so that I should speak of the river, according to the views presented in this paper, as having three terraces. Near Beisan, or Scythopolis, Dr. Anderson says there are three terraces—four I suppose by my nomenclature. He does not make an estimate of the height of the two great terraces of the Jordan, though in one place he speaks of banks of stratified gravel rising sometimes 100 feet. Dr. Robinson, in his *Biblical Researches in Palestine, &c.*, describes the valley of the Jordan near the Dead Sea, and says that the immediate valley, which is usually nearly a mile wide, is bounded by a terrace (the first or lowest of Dr. Anderson I suppose) 50 to 60 feet high at its southern part, but not more than 40 feet further north. He also describes a small terrace near the Dead Sea, only 5 or 6 feet above the meadow, which does not extend far up the stream. The width of the whole ghor or valley to its rocky sides varies from 5 to 10 or 12 miles.

Delta and Moraine Terraces.

Very distinct delta terraces may be seen near the mouths of most of the tributaries of the Connecticut and on the branches of those tributaries; but they do not occur usually at the present mouths of the streams, but rather at the point where

they formerly emerged from the mountains, into what is now a valley with terraces, but was then an estuary, or lake, or broad river. The materials, brought down from the mountains by the tributaries, were pushed forward into these expansions of water, and spread, in part at least, over the bottom. As the drainage went on, these subaqueous deposits gradually emerged in the form of deltas, and were subsequently cut through by the streams. The result would be, as I shall shortly attempt to show, that a new set of lateral terraces would be formed in the delta terraces. Hence at present, several of the sections of terraces that have been described on the preceding pages, cross from one side of an eroded delta terrace to the other. This is the case in No. 13, in which the right hand terraces were all formed upon a delta terrace of Deerfield river. The same is true of the left hand portion of No. 25, which crosses the Ashuelot river in Hinsdale, New Hampshire, as also of No. 28 in Brattleborough, which crosses the original delta terraces of West river and Whetstone brook. On Deerfield river, in Charlemont, I noticed good examples of delta terraces on at least three small streams, that come in from the mountains of Coleraine, Heath, and Rowe, on North river, Mill brook, and Pelham brook, as is shown on Plate IV.

The Moraine Terrace is certainly one of the most remarkable of all the forms of surface geology, as it is one of the most difficult to explain. It is now more than twenty years since I first attempted to describe this phenomenon, and though I have called in the aid of drawings, I feel that I have yet given but an imperfect idea of it to those who have not seen it in nature. Wherever I have travelled, however, these singular elevations and depressions of sand and gravel have awakened my attention, and the localities have multiplied beyond the power of memory to recall. I do not, however, recollect to have met with them anywhere, save in such circumstances that in the drainage of a country the spot must have formed a shore sufficiently steep to have arrested and stranded floating icebergs. I will refer to a few localities.

To begin with the eastern part of Massachusetts, we find these terraces near the extremity of Cape Cod, in Truro, of sand, very strikingly piled up and gouged out. At Plymouth they are more gravelly. In passing west from the coast, we meet with the first general rise of the country. In about twenty miles, and all along this ancient coast line in Connecticut, Massachusetts, and New Hampshire, we find these terraces, not quite so high, however, as in more mountainous regions. In the valley of Connecticut river, all along its eastern side, where the alluvial plain abuts against the bounding hills, they are very common. Still more striking are they along the western foot of Hoosac and Green Mountains, in Massachusetts and Vermont. Let any one pass from Dalton, in Berkshire county, to Cheshire, along the Gulf Road, and he will be a witness of this phenomenon in its grandest form. It is very striking, also, in the east part of Granville, in Hampden county, at the west foot of Sodom Mountain, in a region scarcely penetrated by roads.

These singular forms of the surface do not occur in the lowest and most perfect terraces, but generally as a part of the highest in a district. The materials are always rounded and sorted, and water has most unquestionably played an important part in their production. But I am sure that no logical mind, accustomed to geo-

logical reasoning, will doubt that some other agent must be called in to explain their formation; and their position and relative elevation, as stated above, are important elements in forming a theory of their origin. But more on this subject in the sequel.

2. Surface Geology in Europe.

It is not my intention to give even a summary of the facts collected by Mr. Chambers and others upon surface geology in Europe, except perhaps to refer to a few of them; but, having travelled through several European countries since my attention was turned to this subject, I could not but have my eyes open to it as I passed over the surface. The results of my hasty observations I will now give, though aware that they may be comparatively of little importance.

Wales.

It happened that the first country which I visited after landing at Liverpool, was North Wales, and not expecting to go there when I left home, I had not refreshed my memory with the statements of English geologists respecting its surface geology, and, therefore, I passed over its lofty mountains and through its rugged passes, with no hypothesis in mind, or expectation of what I should meet. In going from Carnarvon to Llanberris, I thought the detritus, to the height perhaps of 300 feet above the sea, indicated sea action; that is, the detritus was not coarse drift, but had been worked over by the action of water. Above that height I found occasionally small accumulations of rounded and comminuted materials, in some partially sheltered spots on the sides of the steep mountains. The highest spot of this kind on Snowdon, my barometer made 2547 feet above the ocean; but in the higher, or rather midway heights of Snowdonia, my attention was arrested by the marks of ancient glaciers. I had not then seen a glacier, but the marks were so obvious that I could not hesitate to refer them to that agency, and the conviction is still stronger since I have been among the Alps of Switzerland, and especially since I have learnt the opinion of Professor Ramsey, who has charge of the geological survey of Great Britain. He finds drift in those mountains 2300 feet high, and thinks that there have been two periods of glaciers there, one before and the other since the drift period. But I will give more details on this point in my paper on the Ancient Glaciers of Hoosac and Green Mountains.

I ought to add, that I saw scarcely any terraces in Wales, nor were the ancient beaches at all striking. On Cader Idris I saw none; but east of that mountain, on the road to Machynleth, is a pass, 762 feet above the ocean by my barometer, and there I saw some evidence of a beach. Although there is proof enough that Wales has been again and again, and for vast periods beneath the ocean, and experienced deep denudation, I did not see there as much evidence of its last drainage as in Scotland or New England.

England.

I traversed England in various directions, and yet generally over its more level parts, and did not see much evidence of drift agency, nor many terraces. The latter I did not expect to find well developed, save in regions where rivers are bordered by hills of considerable elevation, so arranged as to form basins. Yet I did expect to see them on the romantic banks of the Wye, but was disappointed; though materials exist, they are not well formed into terraces. And the same is true of all the streams of England where I passed them. Beds of gravel and sand do, indeed, occur extensively, but they seemed to me to be beaches, or rather old sea bottoms, and not terraces, and many of them sandy and gravelly bottoms of former seas, belonging to a period anterior to the drift, being the beds of tertiary strata.

Very probably good examples of terraces may be found in the more hilly parts of England; and geologists describe deposits of drift derived from Scandinavia and Scotland. But they generally make no distinction between drift and remodelled and comminuted drift, which last forms deposits of far posterior date. I think I see in their descriptions, however, marks of what I call ancient beaches and sea-bottoms of postdiluvian date.

Ireland.

I visited only the northeast of Ireland, passing from Dublin to Belfast, through Dundalk, Castleblayney and Armagh; from Belfast, along the coast, to Fair Head, and the Giant's Causeway, and from thence back to Belfast, through Ballymoney, Ballymena, Antrim, and Carrickfergus. A little south of Castleblayney, I met with genuine unmodified drift, scattered over the slate and silurian rocks, and I saw striæ and embossed rocks; the direction of the striæ being from northwest to southeast nearly. Here, also, were frequent examples of what I suppose to be the Swedish *Osar*, viz., ridges of sand and gravel running northwest and southeast, the rounded summit sloping very gradually, especially at its southeast extremity. At the other end the slope is not so distinct, and indeed the ridge is sometimes terminated by some obstruction.

In Col. Portlock's "Report of the Geology of Londonderry, Tyrone, and Fermanagh," which lie north and northwest from the region I am describing, he states "that these trains of sand and gravel are found at an elevation of nearly 1000 feet." He says, also, that "in the eastern parishes of Derry the form of detritus is peculiar and beautiful. It appears like so many streamers attached to each basaltic knoll, and directed from north to south." These ridges are somewhat different from any that I have observed in the United States; or rather, they seem more distinctly to be the result of a current heaping up materials behind some obstruction; precisely, in fact, what we see in the beds of our large rivers, or smaller lakes. Whereas, with us, similar ridges, which I denominate Moraine Terraces, are often curved, have steeper escarpments, and do not seem connected with obstructions.

They do not seem to correspond to the descriptions given by authors of Osars. Yet M. Desor, who is familiar with such deposits in Scandinavia, describes them as occurring around our western lakes; and he refers to the gravelly ridges at Andover, Mass., as of the same kind. As to the latter, taking Sir R. Murchison's description of Osars (Russia, vol. i. p. 547) as a guide, I have doubted very much whether they could be Osars, since they are too crooked, too narrow, and to long, to be produced by a current sweeping past some obstruction, either a rock or an iceberg. Seffstrom regarded the Osar as peculiar to Sweden, though probably wrong in such a view. But I ought perhaps hardly to give an opinion adverse to such authority on the subject. As remarked on another page, I have represented Osars in four places in New Hampshire on Map No. 1, Plate III, viz., at the *Pot-hole Gorge* in Union, near Fabyan's tavern, in the White Mountains, and a few miles south of Conway, on the road to Centre Harbor, and just within the bounds of the town of Eaton. These may be Osars, yet my doubts as to the fact are not all cleared up.

Along the northeast coast of Ireland the streams are little more than brooks, yet the glens are numerous, and I looked into them with interest, expecting to see perfect terraces. But they are infrequent and imperfect. So in the gently undulating region from the Giant's Causeway, through Ballymoney and Ballymena to Belfast, although rocks seldom appear in place, and a coarse detritus covers the surface; yet it does not assume the form of distinct beaches or terraces. They doubtless exist, however, in other parts of the island; and yet, although in the able papers and volumes of Berger, Weaver, and Portlock, on the Geology of Ireland, I find decided evidence of ancient beaches, I have not met with any description of distinct terraces.

Scotland.

I entered Scotland by the way of the Frith of the Clyde, and soon noticed the general resemblance of its banks to those of American rivers. A few miles below Glasgow, two, and sometimes three, terraces were obvious from the steamboat. They were of small elevation, however, not more, I judged, than 20 or 30 feet, and there is no barrier between them and the ocean. Subsequently I passed through the Highlands by the way of Loch Lomond and Glencoe, and thence to the Parallel Roads of Glen Roy. On this route the surface geology bears a strong resemblance to that of New England. At the foot of hills great quantities of modified drift appear in the form of beaches, rather than of terraces. Sometimes, as in the valley near the lead mines of the Marquis of Breadalbane, the coarse gravel is piled up in those irregular masses with deep depressions, which I have called Moraine Terraces. These, both in Scotland and America, have been regarded as the moraines of ancient glaciers. Once I was prepared to adopt this opinion, but since I have seen undoubted moraines in the Alps, I feel compelled to dissent from it. The fatal objection to such an opinion is, that the materials, composing these supposed moraines, have been modified and in a measure sorted by water—a condition never seen in genuine moraines, at least to any great

extent. Fragments of all sizes and shapes are crowded along promiscuously by glaciers, and though some of them are rounded and others ground to powder, there is no separation of one sort and size from another. Wherever we find such separation, however imperfect, we may be sure that the materials, even though originally produced by glaciers, have been remodelled by water. And such are most of those cases which I have seen of supposed moraines in the United States, which I thought strongly to resemble those above alluded to in Scotland. In passing from Fort William to Glen Roy, along the northwest side of Ben Nevis, vast accumulations of such materials occur, which appear to me to have once been sea-beaches or sea-bottoms. In descending towards the Spean on that road, we meet with very fine terraces, sometimes three or four tiers of them. They are, also, seen along the Roy, even beneath the Parallel Roads, where they have been long since figured by Dr. Macculloch, in the Transactions of the London Geological Society.

These Parallel Roads are certainly the most remarkable terraces I have ever set my eyes upon: peculiar from their narrowness and from their perfect horizontality and parallelism. The first fact may perhaps be explained from their occurrence on hills so steep that they could not retain wide platforms of loose materials. The other facts lead the mind almost irresistibly to the conclusion that the body of water, which once filled these glens, must have paused for a time at the successive roads, as it was drained off. But was it the sea, or a lake, whose barrier towards the ocean has disappeared? Did not the markings extend towards the ocean below that point on the Roy river, a mile or two above its mouth, where such large quantities of detritus lie upon its west side, we might say that the valley at that spot was once choked up with detrital matter to the height of the roads, and subsequently eroded. But since the terraces can be traced far down the valley of the Spean, where it becomes quite broad, such erosion never could be accomplished by the river. Nothing but the ocean could have opened such a broad valley. To suppose the space to have been choked up by a glacier, descending from Ben Nevis, does not relieve the matter, because the materials now occupying the valley have been most evidently worn and comminuted by water, and are not the simple moraine of a glacier. Moreover, I noticed that in some places at least, the side of the mountains above the highest road, was covered by such sand and pebbles as constitute the terraces. I did not ascertain whether the same is true to the very top of the hills; yet such was my impression, and if correct, it destroys the idea of lakes and obliges us to admit the presence of the ocean.

But I fear that I am affording ground for the charge of vanity in venturing an opinion on questions which have divided the judgment of so many able men, who have devoted much more of attention to the phenomena than I have. The new suggestions I have made, in respect to the nature of the materials forming the parallel roads and spread over the sides of the valleys, is my only apology.

In ascending towards the higher parts of the Highlands, especially on approaching Glencoe—that most romantic of all the Highland glens—I found the detritus becoming coarser, and the fragments more angular, with slight evidence of being sorted, very similar, indeed, to the unmodified drift of New England. Just at the

entrance of Glencoe, I noticed striæ upon the ledges running nearly N. W. and S. E. At Oban, on the western shore of Scotland, I observed similar markings, having a direction N. 50° to 60° W., and S. 50° to 60° E. A good example, also, I observed upon the railway track at the Rath station, between Glasgow and Edinburgh—to say nothing of the examples pointed out around the latter city by her eminent geologists.

Perhaps it may be superfluous to mention that, on the hill lying directly east of the village of Oban (where I was detained by ill health), Mrs. Hitchcock found detrital accumulations of recent shells from 200 to 250 feet above the ocean. Prof. James Nicol, in his *Guide to the Geology of Scotland*, mentions that a raised beach occurs not far from Oban, but only some 30 feet above the sea. Others, however, may have described the higher beach to which I allude. I noticed among the shells those of Ostrea, Mytilus, Mya, &c.

Valley of the Rhine.

In travelling through Belgium, the most of which appears as if recently reclaimed from the sea, and is, in fact, probably a not very ancient sea-bottom, I saw no terraces nor beaches till I reached its northeast part. In the vicinity of Liege, beds of gravel appear which I regard as beaches; and, as we approach the Rhine, the railroad is tunnelled through a high deposit of this material. Emerging into the broad valley of the Rhine, we find distinct, though not high, terraces. They are such as are sometimes produced by the slow alteration of a river's bed, by the wearing away of one of its banks and depositing a lower bank on the opposite side. Such a terrace, some miles long and 15 to 20 feet high, I saw on the right side of the railway between Cologne and Bonn, near the latter city. The beaches are composed of sorted gravel and sand, but I observed no genuine drift in passing through the Ardennes mountains. A little above Bonn, is one very distinct terrace, on the south side of the river, above the meadow, with deposits like beaches above. Before reaching the Siebengebirge, or seven mountains, are remains of terraces, some of which have a rapid slope down the stream. But possibly these are rocky platforms covered by detritus. Between the Siebengebirge and Aldernach, we pass occasionally narrow meadows, on one side or the other, with terraces, and sometimes beaches, higher up. Generally there are only two terraces besides the meadow. The lower ones at least are composed, as I was told, mainly of *Löess.* One of these terraced basins I noticed opposite Linz, at the mouth of the Ahr; another opposite Niederbreisig. But I think it useless to particularize, as the terraces all have the same general characters. They are usually of rather moderate height and not wide.

Above Aldernach the valley expands, with at least one terrace above the meadows. From Coblentz to Bingen, the river is crooked, and the banks crowd so closely upon it that terraces hardly exist. Above Bingen, terraces appear, especially on the north side. The Chateau of Johannisberg, the property, as I was told, of Prince Metternich, stands upon one of these, not less than 100 feet above the river. Above this place, the mountains recede far from the river, and the

country is undulating, seeming like the bottom and shores of an ancient sea. But the river terraces are few and imperfect. Near Heidelberg, on the north bank, a few are placed along the foot of the hills. At Wiesbaden and Frankfort, the detrital matter appeared to me like old sea-bottoms, and the long sandy plain passed over between Frankfort and Heidelberg, is probably a terrace of similar origin.

For the next 200 miles, between Heidelberg and Basle, I can only say that the valley of the Rhine is broad most of the way, and I saw but a few well-marked terraces, with now and then a beach above them. But I doubt not that examination would show them both to be numerous, though probably not so distinct as in narrow valleys. Upon the whole, I may say that the phenomena of surface geology on the Rhine, as far as I observed them, correspond entirely with those upon the larger rivers of our country.

Switzerland.

We next reached Switzerland, but in passing towards Zurich, through Bruges and Baden, we continued for a time along the south bank of the Rhine. A little beyond Basle, near the mouth of the Birs, terraces are very fine; and, in fact, they continue to be exhibited along the Rhine as far as I followed it, viz., to Mumpy. The two lowest are very distinct, and then we frequently have irregular ones still higher, which I should call beaches. Near Basle, I measured a terrace, the third in height—and, so far as I saw, the highest—which I found, by the aneroid barometer, to be 228 feet above the Rhine, and 983 feet above the ocean. At Rhinefelder, I took the approximate heights of three successive terraces, and observed at least one other below the lowest of these, and also what seemed to me to be beaches above the highest; these are represented on section No. 41. The highest, it will be seen, is 306 feet above the Rhine, and 1226 above the ocean. Further up the Rhine, near Mumpy, I measured what seemed to me a beach, 696 above the river; and found the highest part of the road between Mumpy and Bruges to be 941 feet above the Rhine at the former place, and 1915 feet above the ocean. At this summit, the detritus was perhaps drift, though I thought it had been modified by water subsequently. After leaving the Rhine at Mumpy, we followed up a small stream with terraces, but they slope rapidly towards the stream, and are, properly speaking, glacis terraces.

Around Bruges, where the Reuse and Limmat join the Aar, the terraces are very fine, and may be seen extending down the river several miles. Between Bruges and Zurich, through Baden, we see some terraces on the small streams, but they are not striking. Most of the detritus seemed to be drift, yet somewhat modified.

The northern part of Lake Zurich I found to be fringed by three or four terraces, which are often chosen as the sites of villages and scattered houses. Leaving the lake at Horgen, on the west shore, we ascended the ridge separating Lake Zurich from Lake Zug. Section No. 42 will give some idea of the terraces on that route. Two of the terraces I measured; and the beach represented as 843 feet above the

lake may be only drift, yet it seemed to me to have been modified by water. If so, this gives us a beach 2185 feet above the ocean.

Crossing Righi, I went to Lucerne; next to Bern, and from thence to Vevay, on Lake Leman; thus passing lengthwise through the greater part of the great valley of Switzerland between the Alps and Jura.

North of Lake Zug is a wide plain, but little above the lake, and appearing like an ancient bottom of the lake, as I doubt not it was. On the east shore of the lake, I thought I saw one or two imperfect terraces. Around the western part of Lucerne lake, I saw none that I recollect.

In going from Lucerne to Bern, we ascended the Little Emmen as far as Scupsheim, and then passed over to a branch of the Great Emmen, which, however, we left ere many miles, and passed over an undulating country, where are numerous accumulations of water-worn materials which constitute what I call beaches, or perhaps, more properly, ancient sea-bottoms. Along all the rivers on this route, terraces are common and often quite perfect; for example, a little south of the village of Langnan, in the Emmenthal. I ought, however, to mention that the sandstone along this route sometimes assumes a terrace form, and, where covered by soil, I might have mistaken such a terrace for one composed of detritus. Yet I am sure that many unconsolidated postdiluvian terraces exist on these rivers. On the Reuss, a little out of Lucerne, I measured one that is 267 feet above the lake, and still further on another that is 325 feet above the same. Towards the summit level of the route, near Scupsheim, I measured a detrital accumulation—which, with some doubt, I call a beach—894 feet above the lake, and 2274 feet above the ocean. The summit I found to be 1287 feet above the lake, and 2667 feet above the ocean.

Around Bern, and wherever I travelled on the banks of the Aar, the terraces are well characterized. They consist mainly of gravel and sand; but as we recede from the river, and come to the beaches, the materials are coarser and pass into drift, the boulders rarely exceeding two feet in diameter; yet they are mainly of the older crystalline rocks, while those in place are sandstone.

From Bern towards Vevay, the detritus, till we reach Bulle, beyond Freyburg, is evidently water worn and sorted into terraces and beaches. Some distance beyond Bulle, genuine drift (perhaps the old moraine of the Rhone glacier) began to appear, and continued, so far as I could judge in the fading twilight, nearly to Vevay, where we strike some lake terraces—which Robert Chambers has described as delta terraces—at the heights of 108, 165, and 442 feet above the lake. The highest terrace, or beach more probably, which I passed on this route, my barometer indicated to be 981 feet above Bern, and 2640 above the ocean.

From Lausanne to Geneva, the west shore of Lake Leman is fringed with terraces. In some places I noticed three or four, though not so many are continuous; probably none of them are all the way. Back several miles from the lake, the country appeared to me to be covered with such materials as terraces or beaches are usually composed of. Some of the terraces near the lake I could see, from the steamboat, to be composed of laminated sand and fine gravel. In entering the harbor of Geneva, I noticed several large Alpine boulders.

From Geneva I turned eastward and followed the Arve nearly to its source, on the route usually taken to Chamouny. On looking over Mr. R. Chambers' paper on the valleys of the Rhine and the Rhone, since my return home, I find that he took the same route, and has anticipated some of my observations. I shall, however, give the few which I collected as they appeared to me.

At the south end of Lake Leman, where the Arve from the region of Mont Blanc unites with the Rhone, a mile below Geneva, as it comes from the lake, is a deep accumulation of detritus, through which both the rivers have worn a passage. It was mainly brought down by the Arve, a rapid and tumultuous stream, almost always loaded with matter mechanically suspended. It is in fact the delta terrace of that river and the Rhone, and extends back to the Saleve Mountains. A mile or two east of the city we reach its highest part in that direction, before crossing the Sardinian frontier. I found the terrace there to be 137 feet above the lake. Passing from this level towards the Arve, we find one or two lower terraces: which are composed of pebbles and boulders mixed with clay, not unlike the "boulder clay" of Scotland.

There can hardly be a doubt that Lake Leman owes its existence to this delta terrace of the Arve. But this point will be better understood when I have treated of analogous cases in my paper on Erosions.

As we proceed along the Arve towards its source, we find terraces more or less distinct most of the way to Sallenches, which is 36 miles from Geneva. These terraces for the most part slope with the stream, and they, also, usually slope towards the river, often rapidly, so as to form the Glacis Terrace. In some places, especially where the valley is narrow, there is only a single slope, as is very common in the higher Alpine valleys, where the river runs at the foot of one of the hills.

The materials of the terraces are usually coarse, though sometimes we pass alluvial meadows. But the higher terraces are very coarse, often like unmodified drift. A few miles below Bonneville, I measured a terrace, not the highest, and found it 314 feet above Leman, 1544 above the ocean, and about 134 above the Arve. A little beyond Bonneville, I measured another, which was 372 feet above Leman, and 1603 above the ocean. At Sallenches, I found one which is 581 feet above Leman, 1811 above the ocean, and about 120 above the Arve. Around Sallenche the terraces are fine, but on the north side of the river I suspect the existence of a portion of a former terminal moraine. Still lower on the stream I thought I discovered another, and when we had gone a league or so beyond St. Martins, and began to ascend the enormous masses of coarse detritus unmodified, I could not doubt that we had reached the terminal moraines of former glaciers.

Four or five miles before reaching Chamouny, we pass a long and narrow defile, and as we might have expected, found terraces above where the valley opens, in which Chamouny is situated. A few of them may be level-topped; but they mostly slope rapidly towards the Arve. Chamouny (Union Hotel), according to my barometer, is 3270 feet above the ocean: 3425, according to Johnston's Dictionary of Geography, and 3190 French feet, according to Keller's map.

Some distance above Chamouny, and just beyond the termination of the Mer de

Glace, the Arve valley is blocked up by an enormous mass of coarse detritus, which was probably the right hand lateral moraine of the glacier, when it formerly extended across the valley. It is nearly 200 feet high, as I judged, save that on the north side of the valley the Arve has worn a passage to its bottom through the moraine. Above this barrier was once a lake, and the result has been, that at least three terraces have been formed on both sides of the river. The highest of these terraces I found to be 670 feet above Chamouny, and 4100 above the ocean.

Still higher up the stream, just beyond the glacier, called Argentiere, is another similar moraine, which produced some terraces, less distinct, however, than in the lower basin. I did not pass into the bed of this ancient lake, but took an observation, towards the hamlet of le Tour, on a level with the terraces, as near as I could judge with the eye, and found the height to be 926 feet above Chamouny, and 4351 feet above the ocean; the highest point where I have ever seen terraces.

After passing the summit between the valleys of the Arve and the Rhone, on the Tête Noire Route, we came upon the Eau Noire, which descends into the Rhone. The highest terraces I noticed on the Eau Noire, which are small and of quite coarse materials, are 793 feet above Chamouny, and 4218 feet above the ocean. But the valley of this stream, for several miles on the Sardinian side of its course, affords a fine example of that sort of glacis terrace, which consists of one broad slope towards the stream from the mountain side. The materials are quite coarse, yet rounded, and evidently the result more or less of aqueous agency. Yet along this stream the erosions of former glaciers are quite manifest, high up on the precipices that bound the gorge.

As we descend towards Martigny, on the Rhone, we have a view of the valley of that river some dozen miles up the stream, traversed by the Simplon road. It looks very much like an estuary recently abandoned, and I could see no terraces. The detritus is spread, with nearly an even surface from one steep side of the valley to the other, having a downward slope equal to that of the rapid stream. Such, for the most part, is the character of the Rhone valley half way from Martigny to Lake Leman. Frequently, however, the alluvial sides of the valley slope towards the river in the glacis form, and sometimes I noticed more than one of this kind of terrace, arranged in successive steps, like the level topped terraces. At St. Maurice, where the river goes through a narrow gorge, and the road passes from the Valais into the Vaud, we meet with terraces of the common form, which I found to be 250 feet above Leman, and 1480 feet above the ocean; or on a level with the surface at Martigny. The Rhone, however, at St. Maurice, is 70 feet lower than at Martigny, according to Keller's map.[1]

[1] In several of the valleys of the Alps, I was struck with a singular optical deception, which I have not seen noticed by travellers. In ascending valleys with steep and lofty sides, the road sometimes descends slightly for some distance, in consequence of the detritus, which spreads out over the whole valley. In some cases of this sort, I felt a little anxiety to see the postilion urging on his horses at so furious a rate, down what appeared to me a quite steep hill. But on looking back, I found that we were scarcely descending at all. And, indeed, I found that a great part of the way we seemed to be

France.

I passed from Geneva to Paris, through Dijon and Tonnerre, and from Paris to Boulogne: also from Calais to Lille, in the north of France, but I have not much to say of the terraces. The country generally is too flat and free from mountains to make their occurrence probable. On the route from Geneva to Paris, terraces are uncommon, though the limestone, which I believe underlies the whole country, sometimes assumes this form: as for example, in the hills surrounding Poligny. Around Campanogle river, terraces are well characterized, and at a higher level I saw some beaches. As to drift derived from a distance, I saw no good example; however, I crossed the Jura mountains in the night. In many places the limestone is worn into a thousand fantastic shapes at the surface, and appears extremely jagged; showing that drift agency has not smoothed it down.

Scandinavia.

This country I did not visit, and I allude to it here for the purpose of quoting a remarkable fact, mentioned by Mr. Robert Chambers, in his description of some of its terraces. These he traced at least to the height of 2162 feet above the ocean, and found the highest bearing a strong resemblance to the Parallel Roads of Lochaber, in Scotland. But the fact to which I allude, is this: "that there is a district in Finmark, of 40 geographical miles in extent, which has sunk 58 feet at one extremity and risen 96 at the other." (Ed. New Phil. Journ., Jan. 1850.) If the terraces there are as irregular as in this country, and as much wanting in continuity over wide districts, this would be a very difficult fact to determine. But I cannot doubt that one so familiar with this subject as Mr. Chambers, would be on his guard against confounding different terraces.

3. Terraced Island in the East Indian Archipelago.

Rev. Charles Hartwell, American missionary in China, on his passage thither, took a sketch of Sandalwood Island, on account of its terraced appearance. Formerly my pupil, and knowing the deep interest I felt in terraces, he sent the sketch to me; and in the dearth of information respecting terrace phenomena in that part of the world, I have thought it ought to be preserved. I have accordingly added it to the illustrations of this paper in Plate XII, Fig. 6. It was taken at the distance of eight miles. *a*, is a projecting point of terraces; *b*, the S. E. point of the island; *c*, detached isle west of the point *b*, and near the southern

descending, when in fact there was a slight slope upward. I observed, also, that when we were on one side of a valley, say 80 or 100 rods wide, and where in fact the two sides sloped somewhat rapidly towards the river in the centre, it seemed as if there was a continuous slope to the opposite side, where the steep rocky mountains rose. I shall not attempt to explain these phenomena, though confident that they are not the result of anything peculiar in my own perceptions.

shore. This was the only terraced island seen by Mr. Hartwell during his voyage. He says it is volcanic in part, and the terraced margin may be coral reefs. It is covered with vegetation, sandalwood being abundant.

Other Forms of Surface Geology.

In the commencement of this paper I have enumerated other distinct forms of detrital matter coming within the province of surface geology. I have not studied these so carefully as the terraces and beaches, and, therefore, my descriptions will be short, though I trust they may deserve the attention of observers.

1. *Sea-Bottoms.*

If we find evidence of the existence of shores of ancient seas, we should expect to discover the remains of their bottoms; and if I mistake not, New England, especially in its less elevated portions, does present the gravelly and sandy plains and low ridges, which can be explained only by the former presence of the ocean above them, with its waves, tides, and currents. In the vicinity of Connecticut river, they are less obvious, because in the lower parts of the valley drainage has, in a measure, obliterated the marks of oceanic action, and the materials have been converted into terraces and beaches. The sides of the valley also rise too rapidly to expect many such accumulations of detritus as form sea-bottoms. But when we get into the comparatively low region, within twenty or thirty miles of the coast, in Massachusetts, Rhode Island, and Connecticut, the surface is in a great measure covered with such materials, and in such forms as the ocean must have produced. Though I am not prepared to mark these definitely upon a map, yet I have ventured to define a few of them near the mouth of the Merrimack, and also in Berkshire valleys, in Plate III; I have likewise marked a strip as of this character, along the route of the New London, Palmer, and Amherst Railroads, and from Merrimack river to Saco river, along the northwest side of Lake Memphremagog.

2. *Submarine Ridges.*

I agree with Mr. Whittlesey in the opinion that the ridges which encircle Lakes Ontario and Erie, were probably formed beneath the waters. These lake ridges—the lowest certainly—may not have been *submarine* in the strict sense of the term, though as it is certain the ocean once stood above the western lakes, it is not easy to say at what altitude the waters became first brackish, perhaps, and then fresh.

I have ventured to mark one submarine ridge near the mouth of the Merrimack, on its south side, and to extend it southerly along the coast at least to Ipswich; beyond which I have not attempted to trace it. The highest part of the city of Newburyport occupies the summit of this ridge, which has a slope both towards the ocean and towards the country. This ridge preserves a pretty uniform height, nearly to Ipswich.

This ridge may prove to have been an ancient beach, but its slope towards the interior and its singularity have led me to refer it to a submarine origin. Others, doubtless, will be found along the coast.

3. *Osars.*

I have perhaps already said all that is necessary as to the existence of Osars in this country. I cannot see why they should not occur here as well as in Europe, since all the other forms of modified and unmodified drift are so similar on cisatlantic and transatlantic shores. But what I call Moraine Terraces cannot be referred to accumulations of detritus by a current sweeping past an obstruction; and, therefore, they are not osars, if such a mode of formation be essential. I should be inclined to refer to osars those remarkable trains of blocks, starting in Richmond in Berkshire county, and extending southeasterly several miles, described by me in the American Journal of Science, XLIX, 253; but they are too long to answer Murchison's description. I will mention one or two cases, however, in the vicinity of the White Mountains, which seem to me more like osars than any examples I have met with in this country, though not satisfied that they are so; but I have placed them on Plate III, in order to call the attention of geologists to those spots. One is a remarkable mound of gravel, near Fabyan's Tavern, five miles from the notch in the White Mountains. Its height cannot be less than twenty or thirty feet above the surrounding surface; and its top (measured with the aneroid barometer) is 1537 feet above the ocean. (See a sketch and description of it in Vol. I of the Transactions of the Association of American Geologists and Naturalists, Plate viii, Fig. 10.)

The other case presents us with several ridges of sand, nearly straight, in a valley lying southwest from Adams' Tavern, in Conway, New Hampshire, towards Eaton. The principal ridge may be a half a mile long, terminated on the north by a pond. These ridges seem to me to differ from those in Andover, in being nearly straight; but they need further examination.

4. *Deltas and Dunes.*

Connecticut river has, of course, made some delta-like accumulations at its mouth, but they are not extensive, being probably swept away by tides and currents. The same is true of the smaller rivers of New England, but as I have not studied any of these with care, I pass them by.

The dunes of southeastern Massachusetts have long since been described. They are sometimes quite high and large, requiring vigorous and expensive efforts to arrest their progress. Along the Connecticut valley small ones exist in Hadley, Granby, Montague, and Enfield, Ct., which are slowly advancing southeasterly, in consequence of the predominance of northwesterly winds. These dunes are derived from the sands of one of the higher terraces of the valley.

5. *Changes in the Beds of Rivers.*

1. *On Connecticut River.*

On the maps which I have given of Connecticut and Deerfield rivers, I have marked numerous ancient river beds. These are of two kinds, the most ancient, showing a deserted rocky gorge, where once the stream flowed at a higher level than at present; and the other, a depression in alluvial meadows, once the bed of the stream, and from which it has been generally slowly deflected by the wearing away of a bank. Changes of the first sort probably present us with old river beds of the antediluvian period, as I shall attempt to show in my paper on Erosions; but the latter class are postdiluvian, and sometimes occur in our own times; one good example of which change may be seen along the Connecticut, at the foot of Mount Holyoke. I was surprised to find how numerous these ancient river beds are, and I doubt not that time and further research would bring to light many more than I have exhibited on the maps. I will briefly describe such as I have found. Of some of them I am not quite sure, but generally they are distinct. The antediluvian river courses it is sometimes difficult to distinguish from erosions by the ocean; and the alluvial ones may be confounded with the troughs between glacis terraces.

The most southerly deserted beds of Connecticut river are in Portland, opposite Middletown. The present bed of that stream through the first range of mountains, appears to me to be in a measure postdiluvian. It curves around two hills of considerable height, between which, as it appeared to me, is a former bed of the stream. I feel quite confident, also, that it once ran on the east side of both the hills, at a considerable elevation above the present level.

On the west side of the river, I think I can trace an ancient, though postdiluvial bed of the river, through Wethersfield, passing a little west of the village, and also through the west part of Hartford, so as to unite with the present bed a little above the city, bringing the city upon the east bank, had it then existed.

Along the east bank a depression commences on the east margin of the meadows, in East Hartford, and continues as far as the south part of Enfield. I have not, however, followed the old bed through the whole of this distance, and may be in error.

In the town of Springfield, a similar appearance is exhibited along the foot of the highest terrace on which the United States Armory stands, from a small stream at the south end of the town, to near the mouth of Chicopee river. I think the river once ran where we now find the principal street of the place. An isolated terrace, a little north of the town, marks the west bank of the former stream, as shown on Section No. 3, Plate I.

Commencing in the west part of South Hadley, an ancient bed is marked on the map, passing to the east part of Granby, through a part of Ludlow, thence into the west part of Belchertown, where it passes through the gorge between the east end of Mount Holyoke (or Norwottuck, as the eastern part is called), and the

gneiss hills of Pelham; thence through the east part of Amherst, into Leverett, where it runs along the east base of Mettawampe (Toby), and thence along the east part of Montague, to the mouth of Miller's river. In the south part of Amherst, at a later period, when the waters had sunk below the gorge at the east end of Norwottuck, I suspect that the current ran along the north base of Holyoke, and entered the present bed of the Connecticut, opposite Northampton. At a period somewhat later, I think another bed ran from this same place along the west side of Amherst; thence to Sunderland, at the foot of the higher terraces, where, at the north of the village, it coalesced with the present bed.

In Hatfield, somewhat north of the village, is a distinct ancient bed of postdiluvian date, but of no great extent.

In the east part of Leverett, is a valley which was probably once the bed of Connecticut river, earlier, without doubt, than the bed so distinct along the foot of Mettawampe. The two unite at Amherst on the south, and in the north part of Leverett on the north.

In Vermont and New Hampshire, I have not examined the Connecticut with care enough to discover its ancient beds, save in two places. In Claremont, I think it formerly ran about two miles east of its present bed, from which the old bed is separated by a hill of considerable height. In the southwest part of Piermont, also, I thought I discovered an abandoned bed, but had not time to explore it carefully.

Opposite Mount Holyoke, in Hadley, is an example (referred to above), of a recent change in the bed of the Connecticut, of considerable extent. Formerly the river made a curve here of three or four miles long, while its actual advance towards the ocean was only about 100 rods. Ten or twelve years ago, during a freshet, a passage was cut through this neck, and since that time, the stream has left its old channel, which is fast filling up, and across which Connecticut River Railroad now runs.

2. *In Orange, New Hampshire.*

On Plate III, a distinct ridge of mountains is represented as running from Bellows Falls, in New Hampshire, to the White mountains. It is not intended to convey the idea, however, that such a continuous ridge exists: but only that it is the summit between Connecticut and Merrimack rivers, from which tributaries of those rivers run in opposite directions. In that summit, in the town of Orange, is a depression in the range, through which the Northern Railroad passes, at an elevation above Connecticut river, at West Lebanon, of 682 feet, and of 830 above the Merrimack. Here pot-holes of great size indicate the former passage of a stream of water for a long time, from the Connecticut into the Merrimack valley. In other words, it seems to have been one of the outlets of the waters of the Connecticut valley, where they stood at that height. But this is hardly a case of the change of a river's bed, since no correspondent stream now exists. Two small brooks, commencing in the peat swamps lying on each side of the ridge, and running, one easterly and the other westerly, are all the representatives remaining of

the powerful current that once crossed this spot. It will be more particularly described in my paper on Erosions.

3. *In Cavendish, Vermont.*

On Plate III, Black river and William's river, in Vermont, are seen to run nearly parallel courses. It appears that they were once united: at least the principal branch of Black river formerly ran southerly into the present bed of William's river. Whoever will pass through "Proctorsville Gulf," in Cavendish, shown on Plate III, as an old river bed, will be satisfied that it was indeed once the channel of Black river. Its present summit, raised considerably by detritus, is (by the aneroid barometer) 792 feet above Connecticut river, at the top of Bellows Falls, and about 100 feet above the Black river at Proctorsville; so that if this river were 100 feet higher at that spot, it might run through the gulf. The sides of the "gulf" are quite steep and high, resembling the banks of many of our mountain streams that have been worn deeply by water.

At Duttonville, in Cavendish, two miles lower down the stream than Proctorsville, is another more obvious ancient bed of the Black river. This, also, is filled with detritus where it branches off from the present bed, but within 100 rods of that spot, on the route of the Rutland and Burlington Railroad, we find large and distinct pot-holes; the infallible mementos of a former rapid current. This old bed may be traced some six or eight miles towards Connecticut river, where it unites again with the present channel of Black river. By the detritus which chokes up the old bed, at Duttonville, that river was compelled to turn to the left, where it has worn out a gorge through the rocks nearly 100 feet deep, producing a romantic cataract, called Great Falls; the foot of which is 183 feet below the old river bed. These two cases, belonging as they do in part to antediluvian agencies, will be described again in my paper on Erosions.

4. *On Deerfield River.*

One of these occurs near Shelburne Falls, in Buckland, where pot-holes exist in the sides of the old channel, 80 feet above the present stream, as may be seen on Plate IV. But a description of the spot is reserved for my paper on Erosions.

Where Deerfield river debouches into the valley of Connecticut river, from its mountain gorge, it has formed an alluvial plat of unrivalled fertility. And here is displayed the best example of changes in the bed of a river by alluvial action that I have ever seen. As all the early part of my life was spent in that valley, I became familiar with these ancient river beds, and I have sketched them in Plate IV. Some others, less obvious, perhaps, might have been added: but it will be seen that not less than fourteen are put down on this spot, only four miles long and one mile broad. Nay, from the manner in which rivers in alluvial spots change their courses, viz., by the gradual wearing away of one of their banks, I cannot doubt that every part of these four square miles, save Pine Hill, in the

northern part, and perhaps some limited spots where the village stands, has once constituted a part of the channel of the stream.

In the extreme northern part of Deerfield, only a mile south of the village of Greenfield, occurs an old rocky bed of Green river, a tributary of Deerfield river. Here are pot-holes in the red sandstone, and a gorge in the same, while the present river runs in a channel worn in sand and clay, several rods further west, and at a considerably lower level. (See Plate IV.)

5. *On Agawam River.*

I have traced out three examples on this river of antediluvian date. One is in Russell, on the west side of the present stream. The old bed is filled to a considerable height with sand and gravel, compelling the river to find its way through a rocky barrier.

A second of these beds may be seen to the east of Chester village, at the junction of its east and west or principal branches. A third is some three miles above this point on the east branch. (See my paper on Erosions.)

I might refer to many other examples of ancient beds of rivers, not connected with the Connecticut. But since most of these are older than the alluvial period, they will more properly be noticed in my paper on Erosions. They would not be mentioned here at all, were it not that the accumulation of detrital matter during the last sojourn of the continent below the waters, seems to have been the means of commencing many of those defiles in which rivers now run.

Results, or Conclusions from the Facts.

I shall now proceed to state the conclusions at which my own mind has arrived from the facts which I have observed respecting surface geology, especially terraces, beaches, and drift. And as these conclusions are not based altogether upon the details above given, I shall present a summary of the arguments by which they are sustained, and the collateral facts and considerations on which they rest.

1. Postdiluvian terraces and beaches all lie above the coarse unstratified and unmodified drift, as well as above the striæ, furrows, and *roches moutonnes*, connected with drift. Hence the terraces and beaches are the result of operations subsequent to the drift period.

I wish not to be understood as maintaining that no genuine drift shows evidence of stratification and other modifying effects of water. Such effects do present themselves sometimes in the midst of detritus, which generally, in position and character, affords unequivocal evidence of being true drift. Limited beds of sand and clay are met with sometimes in the midst of such materials, and sometimes we find masses of coarse irregular detritus and scattered blocks above deposits that are distinctly sorted and stratified. But, as a general fact, the sorted and stratified materials lie above the drift.

I wish, also, to add, that it is no easy matter always to draw a line between

unmodified drift and the modified materials of beaches and terraces. The graduation of one into the other is often so insensible, that we cannot tell where the one ends and the other begins. But I shall refer to this again in another place.

2. The successive beaches and terraces, as we descend from the highest to the lowest, in any valley, seem to have been produced by the continued repetition of essentially the same agencies by which the materials—originally coarse drift—have been made finer and finer, and have been more carefully sorted and arranged into more and more perfect beaches and terraces.

This seems to be the general law: at least such is the conviction produced in my own mind. Yet occasionally we meet with limited deposits, as already remarked, of fine materials in the midst of, or beneath those very coarse. This only shows that in certain places the comminuting and sorting processes were carried on at an early date as perfectly as afterwards when they were extended to large areas.

3. By far the largest part of the materials constituting the beaches and terraces is modified drift, in other words, fragments torn from the rocks in place by all the eroding agencies down to the close of the drift period.

This position is proved by the occurrence of drift scratches and furrows over most of the rocks in place, in the valleys as well as on the hills. Indeed, I expect to show in my paper on Erosions, that some rivers have made deep and long cuts through the rocks since that period: for instance, the gorge of Niagara river, from the Falls to Ontario, and the still deeper cut between Portage and Mount Morris, on Genesee river. But in the valley of Connecticut river no such gorges have been worn, since we find the drift striæ in many places almost as low as the surface of the present stream, even at those points where once gorges were worn out. Thus, at Bellows falls, the rocks at the top of the falls, even to the water's edge, exhibit distinct and beautiful examples of furrows and protuberances produced by the drift agency, although the cataract has undoubtedly receded considerably at this spot since that force acted. At Brattleborough the slate on the west side of the river shows drift furrows only a few feet above the river. Here too was once a gorge: but it was worn out earlier than the drift period. At Sunderland, where Mettawampe and Sugar Loaf, between which the Connecticut now runs, were doubtless once united, drift scratches now show themselves almost on a level with the stream. The same is true on the trap rocks at Titan's Pier, in the gorge between Holyoke and Tom, which were once still more certainly united. As to the gorge a little below Middletown, I am not able to speak certainly, yet so far as I could judge, in passing upon a steamboat, I do not doubt the occurrence of drift erosions at a low level.

4. Hence on such rivers as the Connecticut, wherever, indeed, we can find marks of drift agency low down on the rocks at gorges, we cannot suppose that rocky barriers closed those gorges during the period when the terraces were forming; and, therefore, we cannot call in their aid to explain the formation of the terraces.

5. The highest distinct terraces which I have measured above the rivers on which they occur, are as follows: On Connecticut river, at Bellows Falls, 226 feet; on Deerfield river, 236 feet; on Genesee river, at Mount Morris, 348 feet; on the

Rhine, near Rhinefelder, 306 feet. Some of the accumulations of gravel and sand above these might perhaps be called terraces; but I think they are more appropriately called beaches. So far up the sides of the valleys as these banks appear to have been formed mainly by the rivers that now run through them, when at a higher level, and forming a chain of narrow lakes, thus high should I denominate them terraces. But when we reach such a height that the waters producing the banks must have overtopped most of the hills and communicated with the ocean, or constituted a part of it, then they ought to be called, as they undoubtedly were, beaches—it may be the shores of a bay, or estuary, or frith; but still produced more by breakers than by currents, and, therefore, have not a level top.

6. The most perfect beaches in New England vary in height from 800 to 1200 feet above the ocean. (In Pelham, Shutesbury, Whately, Conway, Ashfield, &c.) Others occur less distinct, as we might expect they would be, from 1200 to 2600 feet above the ocean (at Dalton, Hinsdale, Washington, Peru, White Mountain Notch, and Franconia Notch). I can hardly doubt that further examination will discover others at a still greater altitude.

On Snowden, in Wales, I found a few traces of sea-beaches at several altitudes, the highest 2547 feet above the ocean. Still more distinct marks of a beach occur a little east of Cader Idris, 762 feet above the same level.

In the north part of Switzerland, near Mumpy, I measured what I called a beach, 1670 feet above the ocean; on the west side of Lake Zurich, another, a little doubtful, perhaps, 2105 feet; between Lucerne and Bern, near Scupsheim, another, 2274 feet; and between Bern and Vevay another, 2640 feet, above the present ocean level.

7. The number, height, and breadth, of the river terraces, vary with the size of the river, the width of the valley, and the velocity of the current above the place where the deposits are made. Generally the number is greater upon small than large streams, while the height is less. This may be seen upon the subjoined sections. Thus the terraces on the Connecticut rarely exceed three or four; but on its tributaries, where they enter the Connecticut especially, the number rises sometimes as high as ten, as on the Ashuelot, in Hinsdale, Whetstone brook, and West river in Brattleborough, and Saxon's river, at Bellows Falls. In these cases the terraces on the tributaries are formed in the terraces of the principal stream; yet though the former are more numerous they rise no higher than the latter.

8. The river terraces, excepting the delta terraces, rarely correspond in number or in height on opposite sides of the stream. The delta terrace, whenever worn through by a stream, will, of course be of equal height on both sides of the river. When the valley is wide, and several terraces exist on opposite sides, by the eye alone we are apt to imagine an exact correspondence in height. But the application of the level usually dissipates such an impression, as nearly all the subjoined sections, which extend across the stream, will show. Had I carried these sections across the river more frequently, it would have appeared that sometimes no terraces exist on one side, while there are many on the other; or that the number differs much on opposite sides.

9. River terraces usually slope toward the mouth of the stream, to the same

amount as the current descends, and sometimes more. It is on the smaller and more rapid streams that we see this slope most conspicuously; indeed, on these it is so obvious that I deemed measurements unnecessary. I have made only a single one, and that shows the slope in a delta terrace in the west part of Deerfield, which terrace was produced by a small stream called Mill river, which, as it entered the former estuary, thrust forward a quantity of sand marked as a terrace on Plate IV. This deposit would of course be thickest nearest the shore and diminish outwardly. The amount as I measured it by the aneroid barometer, is thirty-nine feet, in less than half a mile, a slope which of course had no reference to that of the current.

I have said that the slope in some cases is greater than that of the stream. To illustrate this, let us refer to the wide and long basin from Mt. Holyoke to Middletown, in which the current of the Connecticut must have been gentle, nor could the tributaries have brought in materials sufficient to fill up the broad valley as high as where it is much narrower. Hence we should expect, that as we pass south from Holyoke, the upper terrace would become thinner and thinner. Such I suppose to be the fact, as stated in my description of the sections in the part of Connecticut valley above alluded to. In a distance of forty or fifty miles, I have thought we have evidence of a descent of more than 140 feet, besides the descent of the river. The only doubt I have in the case, arises from the difficulty of determining whether the upper terrace, to which my sections extend, is continuous throughout this whole distance.

10. Terraces are usually the highest about gorges in river courses. Such is the fact at Bellows Falls, at Brattleborough, at Montague, at South Hadley, and a little above Middletown, where Rocky Hill on the west side of the river produces a narrow gulf for the river. Also between Tekoa and Middle Tekoa, on Agawam river (Section No. 19.) The materials are not accumulated around these narrow passes because they were then closed, for we have shown that since the drift period most of them have not been closed. But the narrowness of the valley at these spots would, to some extent, retard the streams when swollen, and cause it to deposit more of its suspended matter than in the middle part of the basin. In general it is on the lower side of the gorge that the accumulation is the greatest, because there the waters would spread out laterally and produce eddies or ponds. But sometimes it is above the gorge where the terrace is highest, as on Tekoa.

11. The chief agent in the formation of terraces and beaches appears to have been water. The following facts establish this conclusion beyond all reasonable doubt. 1. The materials have been so comminuted and rounded as no other agent but water can do. Glaciers and stranded icebergs may, indeed, crush and sometimes partially round abraded fragments of rock, but they do not produce deposits of rounded and smoothed pebbles, such as form most of the terraces and beaches. 2. The materials are sorted, so that those of different sizes occupy distinct layers. This effect water alone, of all natural agencies, in the form of waves or currents, can produce. The size of the fragments indicates the strength of the breaker, or the current. 3. The deposition of the layers in horizontal or nearly horizontal position, can be effected only by water. In order to produce the level tops of the terraces water must have once stood above them, while currents strewed the mate-

rials along the bottom. So too, though we find more irregularity in the beaches, yet along what was by the supposition once the line of a coast, they are level, while seaward they are rounded and sloping, like beaches now forming.

In the case of moraine terraces, however, I think it unquestionable that some other agent, besides water, must be called in to explain their formation. If masses of ice were stranded for a long time on the spot where they occur, and currents of water had accumulated the sand and gravel around them, and afterwards the waters had retired and the ice melted, it seems to me that the surface would be left in that peculiar condition which the phenomena under consideration present. I can, however, conceive how strong eddying currents alone might pile up sand and gravel to some extent in a similar manner. But when I meet with these ridges, knolls, and depressions, over wide surfaces, and a hundred feet in height and depth, I have strong doubts whether we must not call in the aid of stranded ice. Water, however, even in this case, must have been the principal agent. But more on this subject in a subsequent paragraph.

12. If the preceding conclusions be admitted, it will follow, that at as high a level as we can find accumulations of rounded and sorted materials, we may be sure of the long continued presence of water, since the drift period, or during the alluvial period. Hence I feel sure from the facts which I have stated, that over the northern parts of this country, this body of water must have stood at least 2000 feet above the present sea level; and I might safely put it at 2500 feet: for up to that height I have found drift modified by water. At an equal height have I observed it on the continent of Europe.

13. The water that stood at such a height on the continents, must have been the ocean. For most of the mountains in the United States are below that level, and consequently must have been enveloped by the waters. Not a few instances occur, indeed, nearly all the examples of beaches which I have described are of this character, in which Plate XII, Fig. 4 represents their situation. Between the old beach and the present ocean there are no barriers high enough to prevent the water that covered the beach from communicating with the ocean: and the fact that the surface, almost everywhere, is smoothed, rounded, and striated by the drift agency, even to the bottom of the valleys, precludes the idea that rocky barriers existed when the beaches were formed high enough to shut out the ocean: for those beaches were formed since the drift period.

I know of no way of avoiding the conclusion that these waters were oceanic, unless it be by supposing barriers to have been formed by vast accumulations of detritus and ice, which subsequently disappeared, after having formed and sustained lakes and inland seas long enough to form the beaches. But this must have required barriers, sometimes perhaps a hundred miles long, and in some places at least 1000 feet high. If they once existed, and were formed of detritus, what can have become of it? Was it carried into the ocean? This would have been impossible by the breaking away of the barrier, even though ruptured in several places; and we may not, by the very supposition, call in the breakers of an ocean to wear it away. Was it an icy barrier? Is it not incredible that an embankment of this material, so many miles long, and so many hundred

feet thick, should have been able to sustain for centuries vast bodies of water, while it was comminuting and depositing extensive beaches. I am fully satisfied, that even though the geologist may, in his study, conceive of such icy or detrital barriers, he could not maintain his opinion, were he to stand upon these beaches, and turn his eyes towards the present ocean, and see what an immense mass of materials must be required to fill up the country to the level of his eye, so as to cut off all communication with the ocean. Certainly nothing like such piles have been witnessed in any place on earth. It is true of some Alpine valleys, that their lower ends have been choked with ice and detritus, so as to form ponds above; but where do we find an example, in which the sides of such valleys, many miles long, are formed by the same materials?

Some, I know, consider no evidence of the presence of the ocean decisive, unless it have left marine remains, and such we find in the United States only among the more recent beaches and terraces, for example the clays around lake Champlain, and along the St. Lawrence, at Montreal, &c., which are only a few hundred feet above the sea. Why they do not occur among the more ancient pleistocene strata, I mean the terraces and beaches, I know of no more probable reason, than that animals and plants were not then living in the waters that made these deposits. But that the beaches and terraces were formed by water, no one, who will examine them, can doubt. This being admitted, I am forced irresistibly to the conclusion that this body of water must have been oceanic, for the simple reason that a sheet of water thick enough to reach such spots, must have spread on all sides far enough to form a sea.

It is possible that some may resort to the supposition, that though no high rocky barriers have been worn down since the formation of the beaches and terraces, yet there may have been great changes of relative level since that time, so that places, which are now lifted high above the general surface, may then have occupied depressions where lakes existed. I can hardly believe that any one practised in surface geology would adopt such an opinion, for he will see that nowhere have terraces or beaches been disturbed by any such movements, but retain exactly the contour and levels which they had when deposited. This they could not have done if there had been any appreciable changes of relative level: and to meet the case, such changes must have been very great. The hills, too, that were rounded by the drift agency, present their *stoss*, or abraded sides, to the north, just as they must have done when struck by such agency: and at the foot of other hills, boulders are accumulated, just as they would be, if those hills stood there during the drift period. In short, though there be evidence that the land as a whole has either risen, or the water has retired from it, since the drift period, in thirty years' examination I have never met with a single example of any change of relative level in different parts of the surface by vertical movements since that time; nor have I seen any such changes described, save that sort of see-saw movement which Mr. Chambers found in Scandinavia, and which may have happened, also, in our own country, but which has never disturbed the relative levels in the sense above supposed.

14. It is hardly venturing beyond a legitimate conclusion, in view of the pre-

ceding facts, to say, that all the northern part of this continent, at least all east of the Mississippi, has been covered by the ocean since the drift period. For admit that these waters rose 2000 feet above the present ocean, and how few mountains even, would project above the surface. A few rocky islands only would be seen, the largest around the White mountains and in the northern part of New York, while the chief portions of the land would have disappeared: nor in the opinion of many geologists is the evidence wanting, in the marks of drift agency everywhere, save at the very top of Mount Washington, that all the hills, higher than 2000 feet, save that single peak, were at that period beneath the waters.

15. Admitting the existence of the ocean over the whole, or the greater part of North America (and the same may be said of other continents, with similar phenomena), and a gradual elevation of the land, or a depression of the ocean to commence and continue to the present time, we can see how, by the drainage of the uneven surface, and the action of waves, tides, and oceanic and fluviatile currents, the whole system of beaches and terraces, as well as other forms of surface geology, were produced.

16. Let us begin with the beaches, which must have been formed the earliest. As the elevated portions of the surface began to emerge from the waters, covered probably to a considerable extent by drift detritus, the waves would act upon the shores and comminute the materials, causing them to accumulate in bays and friths. Yet at first the quantity must have been small, both from the limited extent of coast, and deficiency of materials; and if the elevatory movement was rather rapid, the fragments would not be reduced very small, nor thoroughly rounded. Hence the highest beaches might be difficult to distinguish from the drift, especially as the drift, while beneath the waters (I say nothing here of the time or mode of its origination, save that the period was earlier than the rise of the land), would most probably be made to assume a beach-form in some places. If the elevation proceeded equably, the wave-worn detritus might be strewed somewhat evenly over the sloping surface, and not form distinct beaches. But if there were pauses in the movement, we might look for beaches at successive levels. Yet there would doubtless be great inequality in their position and character, nor should we expect, unless the pauses were long, and the quantity of detritus great, that they would form regular fringes around the islands: but rather that they would be found in the successive bays that would be formed in different places, as the irregular bottom of the sea emerged.

I have supposed pauses in the vertical movement: and these doubtless would produce beach deposits at successive levels. But when enough of land had emerged to give rise to rivers, I think we can see how similar beaches might be formed without paroxysmal movements. A river would carry detritus into the sea, which might be spread along the coast by oceanic currents, and form a bank beneath the waters. Gradually would this be raised by new depositions, and by the uniform rise of the shore, until it would reach the surface, forming a marsh at first; and as the process of elevation went on, a dry and raised beach, modified by the breakers while within their reach. But when the river could no longer deposit its sediment upon this bank, it would be carried forward into the water

beyond, and there begin to form a new bank, which in like manner, would at length reach the surface; and then a third bank would be formed, all the while the vertical movement proceeding without pause or paroxysm.

It may be thought that in such a case the sediment would be deposited in one continuous slope or talus: and it would be without a current along the coast to wear away the successive banks on the outer margin; and thus, it seems to me, the result might be terraces, or rather successive beaches, at different levels. And thus might the lower beaches, that now fringe the coasts of North America, have been formed by a secular and perfectly uniform elevation of the continent. Until rivers existed, however, I should expect the beaches to be very irregular and indistinct, unless there were pauses in the upward movement: and so I do find them near their upper limit, while the lowest beaches on our present shores, are almost as perfect as river terraces, especially at the mouths of rivers, where perhaps, they should be called terraces.

17. Let us now take a bird's-eye view of the continent, raised high enough to bring nearly all the surface above the waters, which is now above the level of the highest terraces. We see the valleys occupied as arms of the sea, in the forms of friths, estuaries, and bays, and in some places, bodies of water exist, cut off entirely from the ocean. Some of the estuaries, too, are so narrowed in particular places, by the approach of barriers on opposite sides of the estuary, as to form, as it were, a chain of lakes, connected by straits. Such would be the aspect at the time supposed of the Connecticut valley. Along the shores, we see on a diminished scale, those rivers which are now its tributaries, emptying into the lake-like estuary, and thus producing a current towards the ocean. Their waters, acting on the drift over which they run, would comminute and carry into the estuary the smaller particles, and thus form shoals, or banks, along their mouths. Meanwhile the ocean is sinking, and at length these banks will come to the surface, and constitute small deltas to the rivers. The streams, too, will wear down their beds, as the estuary sinks, and hence they must cut passages through their deltas, and urge forward a new mass of sorted materials into the now diminished estuary. Thus another delta may be formed, and even a third, or fourth, in the same manner; and even though the vertical movement be perfectly uniform, the current towards the ocean, produced by the tributaries, will so act upon the outer margin of the embankments, as to form terraces, rather than a simple talus.

In this manner, it seems to me, may the delta terraces have been formed by the slow drainage of the country, and without supposing pauses in the vertical movement. These are in fact, among the most usual and striking of the terraces.

Though formed in essentially the same manner as the beaches above described, they would be more regular on their tops, because not exposed as the beaches were, during their emergence, to the action of the breakers.

Mr. Charles Darwin, I believe, first suggested the mode in which delta terraces were formed, as described above, in his paper on the Parallel Roads of Glen Roy. Mr. Robert Chambers, however, has pointed out a case in Switzerland, which fully confirms these views. In the canton of Unterwalden, the lake of Lungern has been artificially lowered within the last sixty years. Where the head of the lake

formerly was, and into which a number of small streams formerly emptied, several deltas are laid bare by the draining off of the water, and they are cut through by the streams, which have worn deep chasms through the loose materials, and are still wearing them backwards towards the Alps.

18. We will now inquire, how, in like circumstances, lateral terraces may have been formed. As the comminuted and sorted materials are projected into the main valley, now an estuary, which, as it sinks, is putting on the characters of a river, they will be swept towards the ocean by the current, a greater or less distance, according to the velocity of the stream. Thus will the delta terraces of the tributary, become in part lateral terraces to the principal valley.

19. There is another mode in which lateral terraces may be formed, as suggested by Robert Chambers, in his paper on the Valleys of the Rhine and the Rhone. In the successive basins that form the chain of lakes produced by the drainage of a country, the detritus brought into the basins by their affluents, will more or less be spread over their entire bottoms, although, as above suggested, banks may be formed, also, along the shores. The materials there spread over the bottom, may accumulate to a great depth, if the straits connecting the several expansions of water are narrow, and the water not so deep as in the basins. At length, however, as the drainage goes on, the bed of the basins will be brought to the surface, and the waters, narrowed into a river, will cut a passage through the detritus, leaving probably on each shore a terrace of the same height. The current, however, might crowd so closely upon one side of the valley as to sweep away all the detritus there, and leave a terrace on one side only.

20. There is a third mode in which lateral terraces might be, and doubtless have been formed. In the case last supposed, the river is represented as simply cutting a chasm through its sandy, clayey, or gravelly bottom. But powerful freshets occur not unfrequently on all rivers: and in their swollen condition, and with increased velocity, they act powerfully upon their banks, especially if of alluvial materials. And if the course of the stream be tortuous, as is always the case, one bank will be acted upon more powerfully than the other. This action will produce a meadow on one side of the stream, but little raised, it may be, above the river in its ordinary state. Successive inundations will eat away the bank more and more, and thus widen the alluvial flat. The stream will thus be spread out over a wide surface during its floods, and of course its velocity will be lessened. This will cause a deposition of suspended matter to take place, whereby the meadows will increase in height. Meanwhile the stream will continue to wear its channel deeper, the supposition being that the drainage is still going on. At length the channel will become so deep, and the meadows so high, that even in freshets the waters will not spread over the meadows. They have now become a permanent terrace, bounded by the river on one side, and by a steep escarpment on the other, that leads to the higher terrace.

As the river no longer rises over the meadows in time of floods, the process already described is repeated, and a third terrace is the result; and so a fourth, a fifth, &c., may be formed, if the river sink deep enough and time be given.

21. A modification of the above process may in some cases be witnessed. The

stream sometimes wears away one of its banks to such a depth, that the channel gradually changes towards that side, while the back water produced on the other side causes a deposit, which is increased by freshets, and although its upper surface becomes nearly level, it yet forms a terrace which properly deserves the name of a glacis terrace. After this process of lateral change has gone on for some years, it not unfrequently happens that the river suddenly deserts its old bed, in consequence of having found a new channel. Successive floods fill up the deserted bed, sometimes so as to make a level-topped terrace: but in other cases, it is only partially filled, and exhibits, at least for centuries, evidence of the former presence of the stream. Such are the old river beds in Deerfield meadows, shown on Plate IV. In the short one directly west of the village, the whole process has been gone through since my boyish days, and I have watched its progress with interest from year to year.

22. It is I apprehend, by modifications of this process, that that variety of glacis terrace exhibited on section No. 31 was produced. Sometimes they may also have resulted from the accumulation of sand and loam on one shore, by the lateral influence of a strong current. I am not prepared to say exactly how that variety of glacis terrace, found in the Alps and other mountainous districts, consisting of rather rapid slopes of the whole alluvial formation of a valley towards the stream, was produced. It may, however, have resulted from the sliding down of detrital matter towards the stream from the steep adjoining hill-sides, during the semi-fluid condition of the surface in the spring, or after powerful rains.

23. On the supposition above made, that during the drainage of a valley like the Connecticut, it assumed the condition of a chain of small lakes, we can see how it is, that around the gorges or straits between them, the terraces should be higher than in the wider parts of the valleys. For the contraction of the stream at the gorges, would check the current there, and thus cause more of the suspended matter to be deposited. Very probably it might so fill up the gorges, that, as the continent rose, it would require a great length of time to wear them down to their present depth.

24. We see then that the various forms of river terraces, whether called delta, lateral, gorge, or glacis terraces, may be formed by the simple drainage of the country, as the surface emerges from the ocean. Nor need we, as has generally been thought necessary, suppose that there were pauses in the vertical movement. That such pauses may have occurred I admit, and that in this way some terraces and beaches may have been produced; but to form the river terraces we need not call in their aid.

25. I now proceed a step further, and will state certain facts, which prove that river terraces in general could not have been produced by pauses in the vertical movement of the land.

1. If thus produced, they ought to be the same in number and height in the different basins of the same river, and on different rivers not very remote from one another. For, even though we might admit some small difference in their height if thus produced, their number must correspond, since the water would sink equally in the different basins. But a reference to the sections attached to this

paper, and to the tabular heights of the terraces, will show that the facts are widely diverse from this supposition. Along the Connecticut, indeed, the most usual number is three or four: but on some of its tributaries they rise as high as eight or ten. Which number, in such a case, shall we assume as indicating the pauses in the vertical movement? If the smallest, then how are we to explain the excess? If the larger number, then why did not the waters leave traces of their influence alike numerous wherever they acted an equal length of time.

2. On this supposition, the terraces ought to agree essentially, at least in height, on opposite sides of a valley. Circumstances might, indeed, erase all traces of their action in particular spots, but such great irregularity as exists in this respect, cannot be thus explained. Terraces thus formed would leave evidence of their existence, as the Parallel Roads of Lochaber have done, on the steep flanks of the Scottish Highlands; which I am willing to admit were produced by successive uplifts of the land, or subsidence of the waters.

3. The difference in the number and height of the terraces upon the principal stream and its tributaries at their debouchure, affords decisive proof that said terraces were not the result of the paroxysmal elevation of the land. Here we find two sets of terraces formed in the same bank of detritus; one set, usually the smallest in number, on the main river, and the other set, formed by the erosion of the tributary through the first. Of these, the maps and sections appended, afford numerous examples. Thus, at the mouth of the Ashuelot river, in Hinsdale (No. 25), we have five terraces on that river, and three, or perhaps four, on the Connecticut. Just below Bellows falls, we find at the mouth of Saxon's river (No. 30), as many as six terraces, while on the Connecticut, a little to the south, in Westminster (No. 29), are only four. In the north part of Vernon (No. 26), are only four on the Connecticut: but on West river, in Brattleborough, perhaps two miles north, we find nine, and on Whetstone brook, ten (No. 28 and Plate III). Moreover, the latter rise no higher than, if as high, as the former. And since both sets are found in the same bank of sand and gravel, it is certain, that if one set were produced by pauses in the retiring waters, the other set could not be: since no possible reason can be assigned, why in the same bank of materials, the terraces on one stream should be twice as numerous as those on the other, if produced by pauses in the retiring waters.

26. These facts, especially the last named, afford almost equally strong evidence that river terraces could not have been produced by the sudden bursting of barriers. In the valley of the Connecticut, if such barriers existed, they must have consisted of sand and gravel, choking up the gorges, and not of solid rock, since the traces of drift agency occur so low down at those gorges. That detrital barriers may have existed to some extent, perhaps with the addition of ice, I will admit. But that they had little to do with the formation of terraces, is clear from the above facts; since if suddenly lowered they could not have produced a different number of terraces on the principal stream from those on the tributaries, nor such irregularity as we find in their height and number upon opposite sides of the river, although they might have formed more in one basin than in another.

27. In a former paragraph (11) I have given an intimation of the views which

I have been finally led to adopt, as to the formation of moraine terraces. I regard them as mainly deposits by water, urged in currents through the sinuosities of stranded icebergs. The subsequent melting of the ice, as the surface was drained, would leave it with those convolutions and anfractuosities, so like those upon the human brain. That powerful currents occur among stranded icebergs, we have the testimony of Sir James Ross, who "mentions that the streams of tide were so strong amid grounded icebergs at the south Shetlands, that eddies were produced behind them; so that as far as such streams were concerned, they acted as rocks. Navigators have observed icebergs sufficiently long aground in some situations, that even mineral matter might be accumulated at their bases in favorable situations, while tide currents may run so strongly between others, that channels might be cut by them in bottoms sufficiently yielding, and at depths where the friction of these streams would be experienced. Much modification of sea bottoms might thus be produced by grounded icebergs, &c." (*De la Beche's Geological Observer*, p. 254.)

Such masses of ice are liable, at some seasons of the year, to be crowded forward by other ice, so as to plough furrows in the loose materials, and grind down and striate the rocks in place. Sir Charles Lyell quotes an interesting case, in which mounds analogous to moraine terraces were produced "by the pressure of ice." From the account given by Messrs. Dease and Simpson, of their recent Arctic discoveries, we learn, that in lat. 71° N. long. 156° W., they found "a long low spit, named Point Barrow, composed of gravel and coarse sand, in some parts more than a quarter of a mile broad, which the pressure of the ice had forced up into numerous mounds, that viewed from a distance assumed the appearance of large boulder rocks." (*Lyell's Principles of Geology*, p. 230.)

Such statements, especially the last one, give great plausibility to the theory which I have adopted. It is still further strengthened by the fact, that these moraine terraces occur in spots, which must have been the shores of the ocean, or of estuaries, or of lakes, as the waters were retiring; and, therefore, just the spots where icebergs might be expected to get stranded. They are found, also, as a part of the earlier terraces, not long posterior to the drift, while as yet we may presume the temperature was low enough to allow of the long continued presence of ice along the shores.

But though the preceding views may explain the rounded hillocks and intervening depressions of the moraine terraces, something more seems necessary to account for those remarkable ridges of sand and gravel, usually more or less serpentine, that accompany the mounds in some instances, as at Andover. Now in high latitudes the shores are found sometimes to be composed of layers of sand, gravel, and ice, more or less interstratified; that is, the waters throw up gravel and sand upon and among the ice along the shores. As the ice melts away, we might expect ridges of sand and gravel to remain, being crooked or straight as the shores were. It seems to me that this may have been the origin of such ridges of this kind, as have fallen under my observation, the most striking of which are in Andover, Mass.

I have seldom been so much perplexed to find a name for any natural object as

for these moraine terraces. Without some new term they cannot be referred to, without much circumlocution. In my Reports on the Geology of Massachusetts, and in a paper on the subject, in the first volume of the Transactions of the American Association of Geologists and Naturalists, I called them, in the first work, *Diluvial Elevations and Depressions;* and in the other, *Iceberg Moraines,* but these terms are quite unsatisfactory; and after having ascertained that these objects are connected with, and frequently form a part of, one of the higher terraces, I have named them, merely on the ground of some external resemblances, *Moraine Terraces,* which I shall use only until I can find a better term.

I have not gone into minute details respecting these curious forms of modified drift, because they are given in the works above referred to, and in my Elementary Geology. By recurring to those details, the reasons will be obvious why we cannot explain the phenomena by water alone, nor by ice alone. Their conjoint agency, it seems to me, may do it.

I ought to add, perhaps, that I have sometimes seen appearances in the bottom of an old river bed, somewhat analogous to the moraine terraces. As such a bed was being filled, when beneath the waters, with sand and gravel, spots were left here and there, several feet deep, which were not filled for want of materials, or from the direction of the currents. But I cannot believe that depressions so deep and numerous, and separated by ridges so narrow and steep, as some of the moraine terraces exhibit, could be the result of mere currents of water.

28. As to lake terraces I can say but little with much confidence. I cannot doubt, however, that those around most of the small and narrow lakes, such as those of New York and of Switzerland, fall into the same category as the river terraces, while yet the water was high enough to form chains of small lakes. For the drainage of the modern lakes appears to have been going on in the same manner as the estuaries, that become ultimately converted into rivers. Such seemed to me to be the case with Lake Zurich and Leman; and such, I am told, is the fact in respect to the smaller lakes of New York, so that they do not seem to require us to call in any new principle besides those already applied to river terraces.

As to the larger lakes, I have had no opportunity to examine any of them, save the one called the Ridge Road, of Ontario, which has more the appearance of a beach, or rather a submarine ridge, than a terrace. Professor Agassiz describes those around Lake Superior, as varying very much in number in different places, "six, and rising from the height of a few feet, to several hundred. He says, that ten, even fifteen such terraces may be distinguished on one spot, forming, as it were, the steps of a gigantic amphitheatre." He distinguishes between these lake terraces and the delta terraces, at the mouths of rivers, which he also describes: and he states also, that the lake terraces "present everywhere undoubted evidence, that they were formed by the waters of the lake itself." He supposes that the shores of the lake have experienced vertical movements; first a depression and then a rise, and that "these various terraces mark the successive paroxysms or periods of re-elevation" (p. 104, *Lake Superior,* &c.). He supposes the terraces to have been formed, and of course the last elevation of the land to have taken place, subsequent to the drift period: for he remarks, "It is clear that the formation

of the terraces was subsequent. They overlie the grooved and rounded rocks" (p. 103). Yet, if I understand Prof. Agassiz, he ascribes these vertical movements to the injections of trap veins, so common along the shores. "This process of intersection, these successive injections of different materials (in the veins), have evidently modified at various epochs, the relative level of the lake and land, and probably also occasioned the modification which we notice in the deposition of the shore drift, and the successive amphitheatric terraces, which border, at various heights, its shores" (p. 424).

Now, with so little personal knowledge of lake terraces, it may be presumption in me to call in question any of these conclusions. But a few suggestions may not be improper.

Were Lake Superior, itself an ocean, alone concerned, we might have less difficulty in admitting these views, and in supposing that its terraces mark the pauses in the uplifts of its shores. But I apprehend that scarcely a lake exists in our country that does not show distinct terraces, nay even ponds, covering only a few hundred acres, exhibit them distinctly. I know of some such in New England. Now surely we cannot suppose that the shores of each of these smaller lakes and ponds have undergone any *such* elevation since the drift period: I mean to say that they have been elevated only as a part of the continent, and not by a local movement, as must have been the case if the shores are raised above the waters. So that if we could dispose of the Lake Superior terraces in this manner, those of other lakes would still remain unaccounted for. Moreover, as to the cause assigned for this rise of the shores, viz., trap dykes, I do not see how these could have been concerned in the last movement which produced the terraces. For the surface of these dykes is smoothed and striated by the drift agency, which shows them to have been injected long before the drift period, whereas the terraces have all been formed since.

I agree with Professor Agassiz in the opinion, that subsequent to the drift period, our continent has been beneath the ocean, and has subsequently risen. But it seems to me that it came up bodily, or as a whole; at any rate, I have not met with any evidence of local elevations. Supposing it was the ocean that spread over all our continent; as that was gradually raised, the waters might have left evidence of their recession, and of their successive pauses (if any prefer that view), in the form of terraces around all our lakes. I think that a rise of the land, unattended by paroxysms and pauses, may more easily show us why the number and height of terraces differ so much on different bodies of water, and that the unequal number which we find on the same lake, or river, may thus be more satisfactorily explained. For if there were such pauses to any great extent, I do not see why the number and height of the principal terraces should not correspond everywhere, even though we leave out of the account the irregularities of the minor terraces. Yet I admit the occurrence, occasionally, of such pauses. I could not, for instance, look on the Parallel Roads of Lochaber, in Scotland, without feeling that probably they mark paroxysmal movements of the waters. But it cannot be denied that men, even geologists, are too prone to resort to paroxysms and irregular action to explain phenomena; and I look upon the labors of Sir

Charles Lyell as of great value in this respect; although I might suppose that his views of uniformity are sometimes carried too far. The rule which I theoretically adopt, is, to admit paroxysms wherever there is evidence of their action, but not introduce them for the sake of eking out an hypothesis. For we ought ever to remember, that in nature, uniformity is the law, and paroxysm the exception.

I will only add, that if it be admitted that the facts adduced in this paper prove the presence, since the drift period, of the ocean at the height of 2000, or even 1200 feet, above its present level, then it must have extended over nearly all of our western country; and unless Professor Agassiz says that he had his eye upon this matter along the shores of Superior, I cannot avoid entertaining the expectation, that what I call beaches will yet be found at a much higher level there, than the 331 feet terrace, measured by Mr. Logan.

29. The period when the formation of beaches and terraces commenced was immensely remote. The proof of this position will more appropriately be given in my paper on Erosions. I trust there to prove, that the whole of the gulf between Niagara falls and lake Ontario has been worn out by the river since the drift period: as well as the gorge between Portage and Mount Morris, on Genesee river, and several analogous gulfs in other parts of the country. I expect also to show, that some of the old river beds, pointed out in this paper, were beds through which rivers ran before the continent went down beneath the ocean the last time. Such facts, if admitted, give an antiquity to the drift period little imagined heretofore; and may excite astonishment that the drift striæ should be so fresh and distinct

30. The facts and reasonings that have been presented, exhibit to us one simple, grand, and uninterrupted series of operations, by which all the changes in the superficial deposits since the drift, have been produced. We see the continent slowly emerging from the ocean; rivers commencing their wearing action on the islands; waves and oceanic currents meeting the detritus of rivers and comminuting, sorting, and arranging the same, in the shape of beaches and terraces, while it may be that icebergs and glaciers modified the whole. It may be, too, that paroxysmal movements occasionally accelerated, retarded, or modified, the effects. The period over which the uninterrupted operation of these agencies can be traced, may be regarded as the alluvial, and we can refer them back at least to the tertiary epoch.

31. It is obvious, however, that it is only the present form and admixture of the loose materials on the earth's surface, that can be referred to the post-tertiary period. We infer that their present arrangement is post-tertiary because they lie in some places above the tertiary. In others, however, they lie upon older rocks—sometimes upon the oldest known. And in such case, though the presumption is strong that their present disposition and mixture are not older than the tertiary, yet the time of the abrasion, comminution, and rounding of the fragments, may have been vastly earlier—as early, indeed, as the consolidation of the rocks on which they now repose. They may have formed other terraces and beaches on other continents; and it is quite possible that in some cases those old terraces and beaches may still remain, not having been remodelled by the last vertical movement of the continents. In an important sense, therefore, the alluvial period may have been

contemporaneous with all other periods; or rather, each period had its alluvium, and sometimes the same alluvium may have belonged to successive periods. These facts give a peculiarity to the alluvial formation possessed by no other.

32. It appears that the time since man came upon the globe, has been only a small part of the alluvial period. For we find none of his remains, nor works, except in the superficial portions of the terraces. The lowest of these, save alluvial meadows, are often the seat of his most ancient works—his habitations and forts. The remotest epochs of history rarely, if ever, reach back to the time when the most recent terrace, save overflowed meadows, was formed. Even if it be admitted, which yet requires proof, that his remains are found with those of extinct animals, this by no means throws back his origin, as has been supposed, to what is usually understood by the drift period, for many races of animals have disappeared since alluvial agencies have been at work.

33. A large proportion of those superficial deposits in high latitudes, that have been usually included in drift, appear from the views that have been presented, to have been the work of agencies greatly posterior; analogous probably to those that produced the lowest and coarsest drift, but still greatly modified. These agencies have taken the drift and worked it over, and though the same kind of drift as the oldest is still produced in some parts of the globe, yet it is undesirable to confound modified with unmodified drift, since it embarrasses our reasonings as to the origin of that coarse deposit which usually lies beneath all others that are unconsolidated, and which all geologists agree in regarding as drift. The superimposed beds of gravel, sand and clay, demand only water to explain their origin; whereas all geologists at this day would agree that the coarse drift must have been the result, in part at least, of glacial action. Besides to blend drift proper and modified drift is almost as much of an anachronism as to regard the conglomerates of the triassic or carboniferous period, as contemporaneous with the fragments of which they are composed.

34. But after all, the idea so long and generally maintained, that the drift agency operated for a certain length of time after the tertiary epoch, and then ceased, and was succeeded by alluvial action, which did not operate during the drift period, I find myself compelled to abandon. For I find evidence that both these agencies have been in parallel operation from the close of the tertiary epoch, to say nothing of earlier periods. They have varied only in the amount of their action. During the earlier part of the period, drift agency largely predominated, as the alluvial agency has since done. Hence the attempt to fix upon a certain definite time when drift agency ceased and alluvial agency commenced, has so signally failed, and scarcely no two geologists have drawn the line in the same place. But I shall recur to this point again after laying down a few more positions.

35. It appears that the organic remains which have been referred to the drift, do, in fact, belong to modified drift, and generally to a very late stage of the alluvial period. The marine remains are the oldest, such as are found on the shores of Lake Champlain, and on the banks of the St. Lawrence, at Montreal; on Long Island, at Brooklyn; at Portsmouth, New Hampshire, and at Portland and other

places in Maine, only some four or five hundred feet above the present ocean; and they occur in clay or gravel that has been thoroughly rounded. These remains (along our coast) belong altogether, I believe, to existing species, and the molluscs even yet retain the epidermis. They must, therefore, have been deposited at a period vastly posterior to the drift. The *Delphinus Vermontanus*, described by Professor Thompson, from the clays near Lake Champlain, was found only one hundred and fifty feet above the present sea level, and hence we should not think it strange that he found it difficult to distinguish it from an existing species.

Still more recent are the remains of extinct land animals, which have often in a general way been referred to the drift. I mean the mastodon, elephant, horse, &c., for they occur most usually in peat and marl swamps, and these may have been quite recent. Such is the case at Newburg and Geneseo, New York, and at the summit-level of the Burlington and Rutland railroad in Mt. Holly, Vermont.

In Wales, marine shells were found nearly 1400 feet above the sea, in what, though called drift, was most probably modified drift, which I saw at even a greater elevation in that country.

36. So far as this continent is concerned, I think we may as yet safely say, that there is no evidence of the existence of life in the seas that covered it during the period of unmodified drift; and, indeed, we might say the same of a considerable part of modified drift and alluvium. I mean that the lowest drift and most of the terraces have not furnished any example of fossil animal or plant. And when we find such proof of glacial agency, especially in the oceans, during those periods, we do not wonder that life was mostly absent. Sir Charles Lyell has also assigned some other reasons for this paucity of organic remains, in the pleistocene deposits, which are probable. (*Manual of El. Geol.*, p. 136.)

37. With such views of the climate in regions now temperate, we should expect, that as mountains emerged from the ocean, glaciers would be formed upon their crests and slopes. Those descending towards the ocean, would produce striæ upon the rocks, radiating from the highest points, or directed outwardly from the axes of ridges, and more or less obliterating the traces of the drift agency, where, as in our country, the striæ that have resulted from it, run nearly in a north and south direction over the whole continent. As far down the mountains as the glaciers extended, they would obliterate, also, the beaches and terraces that may have been formed by the retiring waters.

In Wales, as I have already stated, the marks of ancient glaciers seem to me most manifest, and they have erased most of the marks of the former presence of the ocean, though they do not prove that the country was not all once beneath the ocean, but only that the glaciers have since occupied its higher parts and so changed the surface that the proofs of oceanic agency are less obvious. And, moreover, the ragged aspect of the highest peaks, makes it probable that they never were rounded, as nearly all the mountains in our country are, by drift agency.

In Switzerland, I think we can easily find proofs of the action of water from 2000 to 3000 feet high: but all the regions more elevated, show marks of ancient

or of existing glaciers. And here, also, the lofty summits have not been truncated by glaciers or drift agency.

In America the evidence of ancient glaciers is less striking. I think, however, that I have discovered them upon some of our mountains, and the subject is of such importance, that I have devoted a separate paper accompanying this, to the details of my observations relative to them.

38. Countries corresponding in their modified drift, or rather their beaches and terraces, may be regarded as having occupied about the same length of time in their last emergence from the ocean, and consequently are of nearly the same subaerial age. Perhaps I ought to add, that this principle would require that there should be a general correspondence, also, in the outlines of the surface, and the nature of the rocks, as well as in the rapidity with which the waters withdrew. For, since in my view the terraces and beaches were produced by the drainage of the country, the length of time occupied would depend very much upon the contour of the surface, and the character of the rocks. All these circumstances being the same, I do not see why the time occupied by the drainage should not be the same. In the northern parts of the United States, in Scotland, and Scandinavia, so far as my observation in the two first countries, and information concerning the third, extend, all the above circumstances are essentially alike, and hence I should regard their postdiluvial ages as nearly equal. The facts mentioned elsewhere as to the terraces of the river Jordan, would lead to the conclusion that Palestine and Syria, regarded by so many writers as having experienced great vertical movements, have remained essentially unchanged nearly as long as New England; and the facts respecting the Arabah and its Wadys, south of the Dead Sea, confirm this opinion. This point I have discussed more fully in the first volume of the Transactions of the American Association of Geologists and Naturalists.

39. It is a well known question of great interest, whether the drainage of continents, since the drift period, has been effected by the elevation of the land, or the depression of the oceans. The able expositions of the latter hypothesis, by Professor James D. Dana, in the American Journal of Science, incline me to adopt it, at least partially, some of the facts, concerning beaches and terraces, affording a presumption in its favor. It is not very easy to conceive how a broad continent can be lifted up, and permanently sustained, to the average height of nearly a thousand feet. Still more difficult is it to imagine how this can be done so as not to rupture or disturb the superficial deposits upon it. We should expect that in some places the elevation would be much greater than in others, and consequently the lines of level of the beaches and terraces would be changed, and the materials in some places be disturbed, as they are in regions subject to earthquakes. But I have never met with a single example of such disturbance. And the only case I know of, is the one described by Mr. Chambers, in Finmark, where a seesaw movement, of more than two feet in a mile, has been traced over an extent of 40 miles. Such cases may be discovered in our country; but, so far as I can judge, the change of level has been effected here in the most quiet manner, and the surface has risen in every part alike, and its whole contour remains as when

the waters left it. Such a fact corresponds better with the idea of a retiring ocean than of a rising continent. And upon the whole, though I cannot doubt that lateral pressure and internal volcanic force have produced limited vertical movements; I am more and more inclined to believe that the waters have in a great measure withdrawn in the manner suggested by Prevost and Dana.

40. The phenomena of drift, in distinction from terraces and beaches, although an important part of surface geology, I have not dwelt upon in this paper, because they are now generally known, and, so far as North America is concerned, I have published them elsewhere. But some suggestions upon the theory of drift seem important in this place, in order to bring out my views fully upon surface geology. I have endeavored to show that a large proportion of what has been usually regarded as drift, has been the result of subsequent alluvial agencies. There still, however, remains an irregular coarse deposit beneath the modified beaches and terraces, whose origin is a matter of great interest. The subject is narrowed, but not disposed of. There yet remain the great boulders, mixed with rounded fragments and sand and clay, as well as the striated and embossed surfaces, to be explained. And in respect to the agency by which the phenomena have been produced, the following positions, which are most of them essentially those taken by Professor Naumann, appear to me most unquestionably true:—

1. The eroding materials must have been comminuted stone.

2. They must have been borne along under heavy pressure.

3. The moving force must have operated slowly and with prodigious energy.

4. It must have been nearly uniform in direction, yet capable of conforming somewhat to an uneven surface, and of some divergence when meeting with obstacles.

5. The vehicle of the eroding materials cannot have been water alone.

6. It must have been a firm and heavy mass, yet somewhat plastic.

7. The grinding and crushing mass must have been impelled by such a *vis a tergo*, as would urge it over hills of considerable height.

8. A part of the phenomena can be explained only by the presence and agency of water in some places, at least to sort out, arrange, and deposit layers of sand, clay, and gravel, which are sometimes found beneath the large boulders that are scattered over the surface, or sometimes mixed with the finer stratified deposits.

Were this the proper place, I would quote a multitude of facts to sustain these positions. But since to do this would be less original than the other parts of this paper, I will refer only to a single observation, made by me in the White Mountains, in 1851, and which I have described in the 14th volume, 2d Series, of the American Journal of Science, p. 73, to illustrate the fifth of the above positions. On the southwest side of La Fayette Mountain, near the Franconia Notch, I followed the track of a recent summer slide, which had never been explored. The perils which I encountered in this attempt, greater than I have ever met in a mountain excursion, are detailed in the Journal of Science, but will here be omitted, and I shall give only a part of the facts.

I found a path several rods wide ploughed out by an immense mass of coarse

drift, some of the boulders being from 10 to 20 feet in diameter. They still lie along the borders of the gulf in ridges that correspond exactly to the lateral moraines of Alpine glaciers, and at the end of the slide we have a terminal moraine. The rock in place is laid bare most of the way, and although considerably smoothed, it is not striated to any extent. I cannot conceive of a fairer opportunity to test this matter than on this spot. The size and quantity of the moving mass of detritus, and the rapidity with which it must have descended on a slope of 10° to 38°, were all favorable to the production of an exact counterpart of drift action, if water only was the transporting agent. But it failed just where we should expect it to fail, viz.: in the formation of striæ and furrows.

Where now, save in glaciers, icebergs, and ice-islands, can we find agencies that meet the conditions of the above principles respecting drift? Glaciers, as every one knows, who has observed their effects in the Alps, do produce phenomena corresponding to those of drift in northern regions, in almost every respect. Nor can we doubt that icebergs and ice-floes, large enough to grate along the bottom of the sea, would do the same, although the proof is more difficult to obtain, because the scene of the operation is beneath the ocean. But such icebergs and floes as I suppose, would, it seems to me, operate almost precisely like glaciers. For I assume that they are so large and thick that they reach and press heavily upon the bottom: such icebergs and icefloes in fact, as northern voyagers have described, whose surface was so large that they travelled for days upon them, or their vessel was frozen into them, without their suspecting that they were in motion, till an observation for latitude and longitude showed them that they were upon a drifting mass. Let such masses be put into motion by currents and winds, ever so slowly, and how powerfully would they scour the rocky bottom, wherever they reached it, especially if their under side were armed with fragments of stone.

To which phase of this glacial agency, then, shall we refer the phenomena of drift? Before attempting to answer this question, I shall make a few remarks upon another point, viz.: whether in such a country as the United States and Canada, we can fix upon the geological period when the drift agency operated? Was it previous to the last submergence of the surface, or during its subsidence, or while it was emerging?

There is one fact that leads to the conclusion that the greater part of this work was done before the continent had emerged very considerably from the waters. In my paper on Erosions, I point out several instances in which the beds of rivers, that existed before the submergence of the continent, apparently became so filled with detritus, while beneath the ocean, that the postdiluvian rivers were forced to leave these old channels and wear out new beds, sometimes through solid rocks. True, this detritus is often made up of materials much comminuted, and formed into terraces, and, therefore, may not have accumulated till the continent had been lifted considerably from the ocean. But since these old beds of rivers often show drift scratches beneath the detritus, they must have been made previous to its accumulation, and, therefore, before the drainage had proceeded very far.

On the other hand, there is a fact that leads the mind to the conclusion that the

work of erosion went on for some time after the continent began to emerge. A careful examination of the rounded and striated rocks at different altitudes, will satisfy any one that in the valleys the work is considerably more fresh and less affected by decomposing agencies than on high mountains. The erosions are also deeper in the valleys. Sometimes, as on Holyoke, in Massachusetts, a succession of valleys crossing a mountain ridge, have been excavated, to a considerable depth; but I never saw any such drift valleys on the tops of high mountains. All this looks as if the work at high altitudes was completed first, and continued in the valleys after the emergence of the mountains. Yet, in this country, such anachronism could not have been long continued, for in that case, the emergence of the high mountains would have changed the direction of the abrading force into the valleys, from a north and south direction, and this appears to have been the case only to a limited extent. While only the higher parts of the mountains were above the waters, as islands, they would not very much affect the direction of the force, if it consisted of large icebergs.

Some may imagine that rocks much elevated are more liable to surface disintegration than when in valleys. This may sometimes be true, but I doubt whether, with most rocks the reverse is not the fact. The best example of freshness in rocks rounded and striated at high levels, that I have met with, may be seen on the top of Monadnoc, in New Hampshire, 3000 feet above tide water. Yet apparently it is not as recent there as in the bottoms of some of the valleys.

Upon the whole, I think that we must throw back the drift period with the exception above named, at least as far as the time when this and other countries were sinking beneath the ocean. But did the work take place during that subsidence, or previous to it? My own conviction is, that we have evidence that the work extended into both those periods. If before the time of subsidence, it was accomplished by glaciers on a former continent. If we find evidence, as I think we do, in Wales, in Scotland, in some parts of Switzerland, and in New England, that glaciers existed before the last submergence, the detritus accumulated by them, although modified somewhat by oceanic action, ought to be regarded as a part of the drift deposit. We know, also, that since the emergence of the land, glaciers, in some countries, have been producing genuine drift. It is well known that eminent men have referred the whole of the drift to glaciers, and they seem to me to have proved uncontrovertibly, that the smoothing, rounding, and striating of the rocks in northern regions, have been the result of large heavy bodies of ice, forced along the surface by a *vis a tergo.* Now did the glacier theory apply to other countries as well as to Switzerland, so far as my slight examination of that country enables me to judge, I could not well resist its adoption. But in Great Britain, and especially in this country, there are peculiarities in the drift phenomena, that lead me to hesitate, and inquire whether they are not better explained by the passage over the surface of large icebergs and ice-floes, whose effects scarcely differ from those of glaciers. Some of the reasons for such an opinion are the following:—

1. The occurrence of striæ upon the northern slopes of mountains, even to a

considerable height, is better explained by icebergs than by glaciers. In some instances the grinding body must have been forced upward, above the general surface, which is also striated hundreds if not thousands of feet, as on Mt. Monadnoc and the White Mountains. Now a glacier, descending as a whole in every known instance, is able to force portions of its mass over obstacles a few feet only in height. But here we must suppose one not on a slope, but moving over a level surface for hundreds of miles, to be able to crowd large portions of its mass hundreds of feet over opposing mountains. If we could suppose a huge iceberg, suspended in an ocean rising above the mountains, to impinge against its top, with an immense momentum, it might force a portion of its mass over the top; especially if at the same time the mountain were sinking; though perhaps this descent would be too slow to meet the case.

2. Iceberg action explains better than that of glaciers, that sorting of materials and of laminations, which we sometimes find in the drift. I know it is customary to speak of drift, (I mean the lowest and coarsest variety,) as a mass mingled in perfect confusion. But I have rarely seen a section in it, of very considerable extent, in which I could not discover some marks of the action of water in the parallel arrangement and separation of the materials into finer and coarser. I have often been struck with this evidence of a tumultuous and quiet action in close juxtaposition; and we know that not unfrequently the aqueous action appears to have predominated. But if huge icebergs tore off and accumulated the detritus, we might expect that the currents which bore them onward would, to some extent, separate and arrange the materials, especially where masses of ice were stranded; and that sometimes the icebergs would be absent altogether. Glaciers, however, have no such power, save that the stream which usually issues from them, will cause some alluvial accumulations in the valley below the terminal moraines, but not in the midst of the moraines.

3. The facts concerning the dispersion of boulders can be more satisfactorily explained by icebergs than by glaciers. It appears that the work of scattering these boulders continued till after the time when a large part of the beaches and terraces were formed, for they are scattered over the surface of these sandy deposits. (See Mr. Desor's account of the Drift of the Lake Superior land District, in *Foster and Whitney's Report*, p. 190.) Now glaciers could not have done this; for they would have ploughed a track through the stratified deposits of sand and clay beneath, if they had transported these boulders; and so would such icebergs as I have supposed might have produced the drift below the terraces and beaches. But such icebergs as now traverse the Atlantic might have carried boulders over the beaches and terraces and dropped them from time to time, as we now find them scattered over the western prairies. By the same agency, also, we can explain the intermixture of coarse angular blocks in any of the beach and terrace deposits.

4. The supposition that a glacier once existed on this continent, wide enough to reach from Newfoundland to the Rocky Mountains, is the grand difficulty in the way of the glacier theory. All known glaciers occur in valleys, not many miles

wide, and so did the supposed ancient glaciers, of which traces now exist. But the North American glacier must have extended uninterruptedly almost over hill and valley, for at least 2,000 miles; nor even with that width could it have found higher ground on its borders, unless it were the Rocky Mountains on the west, concerning whose drift phenomena we know but little.

Again, all known glaciers are situated upon slopes, greater or less. Indeed, how could they advance, if not upon slopes? For though expansion by freezing might have some influence in urging them forward, as maintained by authors, yet the facts and reasonings of Prof. Forbes seem to show very conclusively, that gravity is the principal cause of their onward march. At any rate, I know of no example where a glacier does advance upon a level surface—certainly where hills oppose its progress. It is surely, then, a great demand upon our faith, to ask us to believe that the broad North American glacier has crowded southerly 500 or 600 miles, over a highly uneven but not sloping surface, and that simply by expansion. Even should it be proved that we have centres of dispersion in the White Mountains, or the mountains of northern New York, we must still admit a great movement from the north sweeping the whole country, save a few peaks. Nor does it relieve the difficulty to suppose an enormous thickness of the sheet of ice in the arctic regions, from which the great glacier proceeded; for its movement was on the surface of the earth; and this had no greater average height to the north than in the United States.

As to those supposed traces of ancient glaciers, to be described in my paper on that subject, as occurring in New England, the probability is, that they were made earlier than the drift scratches. At any rate, the latter are altogether the most obvious phenomenon, and the principal thing to be accounted for; and it is their characteristics that are reconciled with so much difficulty with the effects of glaciers.

5. I find some difficulty in reconciling to the glacier theory, the diversity of direction taken by the drift agency in different parts of the country. Over the mountains of New England the course was south and southeasterly. But in the valley of Lake Superior, it was nearly southwest. What could have determined different glaciers in directions so diverse, especially as they must have ascended rather than descended, both in New England and to the southwest of Superior, I am unable to conceive. But supposing icebergs to be driven forward by currents in the ocean, and there is no difficulty in accounting for such diversity of direction in the striae and boulders.

Upon the whole, those difficulties seem too formidable to admit of the adoption of the unmodified glacier hypothesis. I lean, therefore, at present, toward that which imputes most of the work on this continent to immense icebergs, icefloes, and shore ice; not because that view is free from difficulties; for I acknowledge them to be many; but they appear less to me now than in the other hypothesis. Perhaps, however, the iceberg hypothesis, as I have stated it, falls but little short of that of the glaciers. For I agree with Professor Agassiz, that to sustain the former, "we must assume an ice period—nothing less than an extensive cap of ice

upon both poles." "This," says he, "is the very theory which I advocate; and unless the advocates of that theory go to that length in their premises, I venture to say, without fear of contradiction, that they will find the source of their icebergs fall short of the requisite conditions which they must assume upon due consideration, to account for the whole phenomena as they have really been observed." (*Lake Superior*, p. 406.) I think that could we get access to the floor of the Arctic Ocean, where the icefloes probably occupy more space than the water, that partially bears them up, we should find a work going on very similar to that which produced the drift. On such icebergs and icefloes, for the present I take my stand. But as I look toward the shore, and see my neighbor standing upon a glacier, I can hardly tell the difference between the two foundations; and whenever he will show me that his glacier is advancing southerly over a level surface, as does my iceberg, I will gladly place myself by his side.

As to the origin of that more intense cold which once prevailed over New England and other countries much farther from the pole than at present, I have no hypothesis to offer. But as to the fact it seems to me that the undeniable former great extension and thickness of glaciers in Switzerland, Scandinavia, Wales, and perhaps Scotland, and the absence of organic remains from drift, in general, make it certain. I have sometimes imagined that the upheaval of the bed of the northern ocean, according to De la Beche, or the earthquake waves of the Professors Rogers, sweeping southerly from the same region, might afford an explanation. But such forces would produce only a temporary submersion and icy deposit; whereas the evidence of the long continued presence and action of water and ice, and of the slow emergence of the land from the ocean, evince its permanent submergence.

41. Let me now present a summary of my present views of the origin of that deposit, properly called drift, excluding all which I have described as modified drift.

1. *Glaciers.*—It seems to me that the moraines of glaciers affords a good type of drift, viz.: a confused mixture of abraded materials of almost every size, driven mechanically forward. I cannot see why we should limit the impelling force to water as does the ordinary definition of the term drift.

If these views are correct (and I presume no geologist will dissent), then we have one agency in this work in which all are agreed, and which is still in operation before our eyes. Moreover it has been at work from the earliest times in which we have any evidence of drift action. Certainly it goes back as far as the tertiary period, perhaps further. Before the last submersion of our continents it may have operated long and powerfully; and if the views of some geologists are true, it then accumulated the great body of the drift now before our eyes. And still in northern regions, and even in central Europe, it is adding to the mass daily.

2. *Icebergs.*—Wherever these reach the bottom and are urged forward, it cannot be doubted that they must produce essentially the same effects as glaciers. And for the reasons already given, I must suppose that in some countries—our own for

instance—most of the drift has been thus produced, and most of the erratic blocks thus scattered.

This agency, too, we can trace back to the dawn of the drift period, and it is still in operation on a stupendous scale in arctic and antarctic regions. What we witness of its effects in temperate seas shows only its power in transporting afar blocks of stone which it has torn from the shore.

3. *Mountain Slides produced by Aqueous Agency.*—If any one doubts whether this should be reckoned among the causes of drift, let him visit the case described in this paper, on what I call *Moraine Brook*, in Mount La Fayette, at Franconia, and he will see first, that the materials torn off from the ledges and strewed along for two miles, cannot be distinguished from coarse drift; and secondly, that they are so arranged as not to be distinguishable from the lateral and terminal moraines of a glacier. Why then should they not be regarded as drift?

4. *Waves of Translation, produced by the Paroxysmal Upheaval of Continental Masses, or Earthquake Undulations.*—Whether any certain example of such a movement can be pointed out—unless we admit drift generally to have been thus produced—I exceedingly doubt. But hypothetically we can realize that such waves would tear off fragments of rocks and roll them along and smooth, if they did not groove, the rocks. This action would, indeed, be too short, violent, and irregular, to explain all the features of drift, which were the work of agents acting ages upon ages: yet, from the phenomena occasionally exhibited by earthquake waves along the coast, we may reasonably include this force among those concerned in the production of drift. And in some countries it may have done much of the drift work.

5. Perhaps I ought to add, as a fifth cause of drift, those ice floods that occur almost every winter in the rivers of northern and mountainous countries. Often in these cases, the river is choked with fragments of ice, so that its banks are full. Yet there is water enough to keep it slowly in motion. It differs, in fact, from a glacier, only in being more fluid, so that its motion is more rapid. But it grates powerfully upon the sides and bottom of the stream, and produces miniature moraines. I see not why such detritus should not be regarded as drift as much as the moraines of glaciers or icebergs.

42. According to these views, drift is the result of several agencies that have been in operation upon the earth's surface, certainly since the tertiary period, and in some countries, from a much earlier date. They have varied in intensity at different times, and in different circumstances, and each one has had a predominance at certain times. But all of them are still in action in some parts of the globe, and perhaps with as much power as ever.

43. In like manner, alluvial agencies have had an operation parallel to those producing drift, and as far back, though the present forms of alluvium are chiefly posterior to the tertiary epoch. But perhaps the whole formation is not so.

44. Drift and alluvium ought to be regarded as only varieties of the same formation. And since water has always been present and essential in the operation of the other agencies, the whole formation should take the name of alluvium. Chro-

nologically, we might divide this formation into the following periods; which, however, must not be understood as completely isolated from one another, but only as marking the times when certain phenomena predominated.

1. The Period of unmodified Drift.
2. The Period of Beaches, Osars, Submarine Ridges, and Sea Bottoms.
3. The Period of Terraces.
4. The Historic Period, or the Period of Deltas and Dunes.

Lithologically, Alluvium may be subdivided as follows:

1. Drift unmodified, embracing angular and rounded boulders, gravel, sand, and clay.
2. Modified Drift, embracing the following forms:
    1. Beaches, ancient and modern.
    2. Osars.
    3. Submarine Ridges.
    4. Sea Bottoms and Lake and River Bottoms.
    5. Terraces.
    6. Deltas.
    7. Dunes.
    8. Moraines.

Such views, essentially, have been advanced by previous writers of great ability. Thus, Sir Charles Lyell groups together all the strata above the tertiary, under the name of Post-Pliocene, of which the Recent embraces the deposits coeval with man, and Drift, those anterior to man. We find, also, that the eminent palæontologist and geologist, M. Alcide D'Orbigny, in his *Cours Elementaire de Palæontologie et Geologie*, comprehends in his *Terrains Contemporains, ou Epoque actuelle*, every thing above the tertiary. Still more specifically like my own, are the views expressed by William C. Redfield, Esq., at the meeting of the American Association for the advancement of Science, at Cambridge, in 1850. He remarked, "that the phenomena of the boulders and drift should be attributed to mixed causes, and that the theories which refer these phenomena to the several agencies of glaciers, icebergs, and packed ice, are, in truth, more nearly coincident than is commonly imagined." I understand M. Desor, also, who has had opportunities for examining drift phenomena, not inferior to those of any man living, as inclined to similar views. He supposes that "the surface boulders, like many of those buried in the drift, clay, and sand, have been transported by the floating ice:" and he says that since "glaciers in our days occur chiefly in the valleys of the highest mountain chains, it is difficult to conceive how they could exist and move in a wide and level country like the northern parts of the United States and Canada." (*Foster and Whitney's Report*, p. 215.)

45. Such are the results to which I have been conducted by the facts respecting surface geology which have fallen under my notice. I am aware that these are subjects of great difficulty, and that I am in conflict with the views of eminent geologists on several points; as I am, indeed, with my own opinions, as held several years ago. And yet for a long time I have stood chiefly aloof from the

various hypotheses that have been broached respecting surface geology. But I could not refuse to follow where facts seemed to lead the way. It becomes me, however, to be very modest in urging my conclusions upon others. If they cannot adopt my explications, I hope they will at least find my facts to be of some little service in reaching better conclusions.

Heights of River Terraces and Ancient Beaches above the Rivers to which they are contiguous, and above the Ocean (mean height), as measured by EDWARD HITCHCOCK *in* 1849, 1850, *and* 1851. *Heights in English feet.*

S. B. prefixed indicates that the heights were obtained by the Syphon Barometer; A. B., by the Aneroid Barometer. In all other cases, they were measured by the common levelling instrument. The figures inclosed in parentheses refer to the sections where the terraces and beaches are represented.

	1 Above the river.	1 Above the ocean.	2 River.	2 Ocean.	3 River.	3 Ocean.	4 River.	4 Ocean.	5 River.	5 Ocean.	6 River.	6 Ocean.	7 River.	7 Ocean.	8 River.	8 Ocean.	9 River.	9 Ocean.	10 River.	10 Ocean.	11 River.	11 Ocean.
ON THE SHORE OF THE OCEAN.																						
Lyme, Ct., beach (33) S. B.		14																				
Lyme, Ct., beach (33) A. B.		19																				
East Lyme beach (ancient) (33) S. B.		31																				
East Lyme beach (ancient) (33) A. B.		31																				
East Lyme River terrace (highest) (33) S. B.		119																				
East Lyme River terrace (highest) (33) A. B.		102																				
Flanders (New London) beach (33) S. B.		34																				
Flanders (New London) beach (33) A. B.		39																				
ON CONNECTICUT RIVER.																						
Glastenbury, Ct., terraces (7)	20	36	50	66	174	190																
East Hartford terraces (6)	15	36	40	61																		
Wethersfield terraces (8)			57	76																		
Windsor terraces (9)	19	44	49	74	114	139																
East Windsor terraces (5)	22	47	71	96																		
Longmeadow terraces (4)	24	88	136	200																		
Springfield terraces (3)	21	85	36	100	67	131	136 (?)	200														
Springfield Willimansett do. (2)	40	114	194	268																		
South Hadley terraces (1) S. B.	182	287																				
South Hadley terraces (1) A. B.	193	298																				
Northampton terraces (10)	57	162	97	202																		
Hatfield terraces (10)	22	130	28	136	38	146	53	161														
Hadley terraces (10)	27	135	54	162	181	289																
Whately terraces (12)	32	146	46	160	92	206																
Turner's Falls, Montague terraces (18)	18	212	97	291	175	369																
Northfield (south part) terraces (19)	24	224	90	290	131	331																
Northfield (north part) terraces (20)	24	224	87	287	112	312																
Hinsdale, on south side of Ashuelot River, near its mouth (21)	7	215	14	222	36	244	66	274	150	358												
Hinsdale, south side of the Ashuelot (21)	7	215	14	222	37	245	73	281	162	370												
Hinsdale, on Connecticut River, beyond the village (21)	21	231	96	306	159	369	Unk.															
Vernon (22)	21	234	38	251	107	320	237	450														
Brattleborough, mouth of Whetstone Brook, towards the S. W. (23)	20	234	74	288	86	300	118	332	165	379	200	414										
Brattleborough, mouth of West River, across the village S. W. (24)	25	239	47	261	58	272	70	284	80	294	100	314	114	328	132	246	221	435				
Brattleborough, on Whetstone Brook (24)	8		14		23		44		56		83		102		138		153		Unk.			
Westminster (25)	24	255	94	325	139	370	171	402														
Langdon, mouth of Cold River, south side (24)	16	251	94	329	243	478																
Westminster, near Bellows Falls, opposite Cold River (24)	26	261	34	269	38	273	83	318	117	352	138	373	161	396	226	461						
Bellows Falls, above the falls (26)	41	327	122	408																		
Pelham, ancient beaches (10) S. B.	583	688	921	1029	1049	1151																
Pelham, ancient beaches (10) A. B.	567	672																				
Shutesbury, ancient beaches	1053	1167	1103 (?)	1217 (?)																		
Amherst, near Mount Pleasant, ancient beach (10)	329	437																				
Whately, north part, beach S. B.	704	809																				
Whately, north part, beach A. B.	690	795																				
Conway (Shirkshire) beach S. B.	942	1047																				
Conway (Shirkshire) beach A. B.	928	1033																				
Ashfield, N. E. part, beach, A. B.	976	1031	1216	1321																		
Heath beach (30)	1438	1561																				

Heights of River Terraces and Antient Beaches—Continued.

	1	1	2	2	3	3	4	4	5	5	6	6	7	7	8	8	9	9	10	10	11	11
	Above the river.	Above the ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.	River.	Ocean.
ON AGAWAM RIVER.																						
Westfield terraces (17)	11	136	25	150	83	208	114	239	134 (?)	259 (?)												
ON FORT RIVER.																						
Amherst to Pelham, south side of the river, terraces (11)[1]	7	172	14	179	31	196	80	185	130	235	180	285	235	340	268	373	323	428				
Amherst to Pelham, north side of Fort River, delta terraces (11)[1] S. B. / A. B.	7	172	14	179	131	236	155	260	176	281	210	305	248	353	318	423	376	481	387	492	429	534
ON DEERFIELD RIVER.																						
Deerfield, Foot's Ferry, south side of the river, terraces (27)	15	155	24	164	Unk.		Unk.		178	318												
Same place, north side of river (27)	15	155	29	169	36	176	94	234	103 S. B.	243 S. B.												
Deerfield, south end of village, towards mountain, terraces (14)	10	140	38	168	122	250	196	326	A. B. 235	A. B. 315												
Deerfield, Carter's land terraces (14)	20	146	64	190	183	309																
Deerfield, Pettee's plain terraces (15)	108	232	159	283																		
Deerfield to top of Pine Hill, terraces (16)	20	143	57	180	95	218																
Buckland, south side of river, terraces (29)	11		21		32		45		75													
Deerfield Mountain, beach (14)	407	537																				
TERRACES AND BEACHES IN OTHER PARTS OF NEW ENGLAND.																						
Peru, Mass., terraces on a brook (32)	46	1813	65	1832	84	1851																
Peru, Mass., ancient beach (32)		2022																				
Washington, Mass., ancient beach summit level of Western Railroad (31)	46	1590																				
Bath, N. H., terrace near the mouth of Ammonoosuck River, A. B.	523	934	[2]																			
Notch House, Franconia beach, S. B.	1524	1930	[2]																			
Notch House, Franconia beach, A. B.	1463	1869	[2]																			
Notch House, beaches west on the road, A. B.	2043	2449	2259	2665	[2]																	
Osar near Fabyan's, White Mts., A. B.	1131	1537	[2]																			
Notch of White Mts., Gibbs's Hotel, beach, S. B.	1667	2073	[2]																			
Notch of White Mts., Gibbs's Hotel, beach, A. B.	1557	1963	[2]																			
ON HUDSON RIVER.																						
Sandy terrace, or beach between Albany and Schenectady (34), A. B.	335																					
Greenbush, opposite Albany, terraces (34), A. B.	64		135		179																	
Beaches on the Western Railroad, east of Hudson River (34), A. B.	330		554		642		890		1111		1378			1590								
ON GENESEE RIVER.																						
Highest terrace east of portage towards Nunda, A. B.	235	1410																				
Mount Morris terraces, west of the river (35), A. B.	73	616	116	659	229	772	348	891														
ON THE RHINE, GERMANY.																						
Near Basle, 3d terrace, A. B.					228	983																
Near Rhinefelder (36), A. B.			102	1022	200	1120	306	1226														
Between Mumpy and Brugg, beaches, A. B.	696	1669	941	1915																		

[1] The numbers in these lists represent the mean height of a series of delta terraces on both sides of Fort river, above that river in Amherst, and above the ocean on the south side. They were obtained by levelling on the north side by both kinds of barometers, except the two lowest. It would, perhaps, have been better to have given the heights above Connecticut river, as is done in the section No. 11.

[2] Above Connecticut river and the ocean.

Heights of River Terraces and Ancient Beaches—Continued.

	1 Above the river.	1 Above the ocean.	2 River.	2 Ocean.	3 River.	3 Ocean.	4 River.	4 Ocean.	5 River.	5 Ocean.	6 River.	6 Ocean.	7 River.	7 Ocean.	8 River.	8 Ocean.	9 River.	9 Ocean.	10 River.	10 Ocean.	11 River.	11 Ocean.
ON LAKE ZURICH.																						
From Horgen S. W., terraces and beach (37), A. B. . . .	263	1605	392	1734	843	2185 [1]																
FROM LUCERNE TO LAKE LEMAN, THROUGH BERN.																						
On the Reuss, between Lucerne and Bern, terraces or beaches, A. B.	267	1647	325	1705	894	2274 [2]																
Between Bern and Leman, terrace, the highest on the road, A. B. .	981	2641 [3]																				
ON THE ARVE.																						
Highest terrace between the Loire and Lake Leman, A. B. . .	137	1367 [4]																				
Near Bonneville, terraces, A. B. .	314	1544	372	1603 [4]																		
Near Sallenches, A. B. . . .	581	1811 [4]																				
Terrace highest at Argentiere, opposite the glacier, A. B. . .	675	4100 [5]																				
Terrace at Le Tour hamlet, A. B. .	926	4351 [5]																				
Terrace on the Eau Noire (highest), A. B.	793	4218 [5]																				
Terrace at St. Maurice on the Rhone, A. B.	250	1480 [6]																				
IN WALES, GREAT BRITAIN.																						
Beach east of Cader-Idris, between Dolgelly and Machynlleth, A. B.		969																				
Highest beach (?) on Snowdon, A. B.		2547																				

[1] Above the lake and the ocean.
[2] Above Lake Lucerne and the ocean.
[3] Above Bern and the ocean.
[4] Above the lake and the ocean.
[5] Above Chamouny and the ocean.
[6] Above Leman and the ocean.

ILLUSTRATIONS OF SURFACE GEOLOGY.

PART II.

ON THE EROSIONS OF THE EARTH'S SURFACE,

ESPECIALLY BY RIVERS.

ON THE EROSIONS OF THE EARTH'S SURFACE.

General Remarks.

The vast amount of denudation which the earth's surface has experienced is shown by the following facts:—

1. The great amount of boulders, gravel, sand, clay, and loam, that is spread over the solid rocks.

That these materials once constituted a part of the solid strata, it would seem, cannot be doubted by any one who has observed natural operations at all. For he must have seen the process of abrasion and comminution going on everywhere. Let him go to the shores of any river, and he will see the work in progress. Where the stream is rapid, the materials at its bottom and along its shores will be coarse and not thoroughly rounded; where less violent in its movement, well-worn pebbles will be seen mingled with coarse sand; that is, such materials as that amount of current would urge along. Fine sand, clay, and loam, will appear where the stream is very slow; because such a current can separate and sweep along only the minute fragments of which such deposits are composed. But in all these cases the fragments, if examined, will be found to be portions of the rocks over which the stream passes; and, moreover, we find in many places that the river, sometimes in the form of ice, has power to break off and grind down portions of the rocks.

Now these detrital materials are spread over perhaps nine-tenths of the surface, even in mountainous regions, save in some very precipitous and elevated parts. Their thickness, also, often amounts to hundreds of feet. In short, the loose materials spread over four-fifths of the surface, amount to a thick rock formation; and all accumulated by the slow processes of erosion now going on before our eyes. How vast the period requisite to accomplish the work!

2. By the deep troughs worn out of the loose materials by rivers. After the detritus has been deposited the stream sinks by wearing away a portion of the mass. This process has sometimes gone on to a depth of 100 or 200 feet; and though this is a small erosion in comparison with that already named, it deserves notice in this connection.

3. Nearly all the fossiliferous rocks are composed of materials abraded from previously existing rocks, and subsequently consolidated. The former, it is well known, are several miles thick in all the countries where they have been measured.

They thus prove an amount of erosion previous to the alluvial period, immensely greater than during the deposition of drift and alluvium.

According to the views of many eminent geologists, I might consider nearly all the crystalline stratified rocks among those originally detrital. But as this is debatable ground, I leave them out, although all geologists, I believe, admit that there are metamorphic rocks of considerable thickness having such an origin.

4. By the rounded, smoothed, and striated appearance of most of our hills and mountains in the northern portions of continents. These phenomena indicate an erosive agency that has operated long and powerfully, especially on the northern slopes of mountains, to wear them down. To this force we might add that of glaciers, which produce similar effects; and as all know, the two agencies are by some regarded as identical.

5. The marks of erosions in gorges and on the steep sides of valleys, teach the same lesson. These, I apprehend, are more common than has been supposed; and it is the chief object of this paper to describe and elucidate them. It is an agency distinct from that producing drift, being referable to two sources, viz: rivers, and the ocean acting upon its shores.

6. But perhaps the vast amount of materials that must be supplied to fill up deficiencies in the strata, shows most strikingly the enormous erosions that have taken place. Facts on this subject have not, indeed, been accurately determined in many countries. Yet we know enough to be satisfied that miles in depth have often been taken away; as indeed we might presume must have been the case to supply materials enough for the sedimentary rocks.

All these facts speak the same language, and impress the careful observer with the magnitude of the work of erosion that has been going on from the earliest times. Yet it is only the careful observer who will be impressed with these proofs. Those who take only general views of the rocks and the surface geology, can easily persuade themselves that even the fragmentary rocks were created just as we now find them; and some extend such an hypothesis even to the water-worn pebbles and banks of sand.

Agents of Erosion.

It may be well briefly to enumerate the agents of erosion upon the earth's surface before detailing their effects. They may all be grouped under Atmospheric Air and Water.

1. *Atmospheric Air.*

The four constituents of atmospheric air, oxygen, nitrogen, carbonic acid, and aqueous vapor, are all concerned in the disintegration of the solid rocks, which thus become prepared to be easily acted on by mechanical agencies. Probably oxygen, of which so great a quantity exists in the air, is the most efficient of these agencies, since it has so strong an affinity for most other substances that they will quit their weaker combinations to unite with it. Peroxidation, also,

from the same cause, is very common; as in the case of iron and manganese, which are almost universally present in the rocks and the soils.

Nitrogen seems rarely to operate directly upon the rocks: but when converted into nitric acid and ammonia, as it sometimes is, these compounds act with much energy as disintegrating agents.

Perhaps carbonic acid is the most efficient of all agents in the work of erosion. But as it acts chiefly when dissolved in water, I reserve details to the next head. And as to aqueous vapor in the atmosphere, its effects upon the rocks, are not so marked as to be easily described, although doubtless it assists the other constituents of the air in this work.

2. *Water.*

Water acts upon rocks and minerals in three modes, in all of which it is energetic.

1. *As a medium for other decomposing agents.*—These it dissolves, and thus enables them to act upon the rocks. Carbonic acid should stand at the head of this list. It seems to be the only acid, with a few rare exceptions, that exists in the water, which penetrates the rocks, and is able to decompose the silicates of alkalies, the alkaline earths, and protoxides of iron and manganese, at ordinary temperatures. The alkaline carbonates when formed, will decompose solutions of sulphate of lime, or manganese, and the chlorides of calcium and magnesium. Chemical changes thus begun, others will follow in a wider range, all commencing with carbonic acid.

Bicarbonate of lime is another agent widely diffused and productive of extensive changes: such, for instance, as the formation of carbonate of lime, the most abundant of the salts formed in the earth's crust.

The alkaline carbonates are not so generally found in natural waters: but whenever present, as the result of other agents, they effect important changes, such as prepare the way often for erosions by mechanical agencies.

2. *Water, alone, dissolves not a few of the ingredients of rocks.*—The process is much slower generally than when aided by carbonic acid. Nevertheless, pure water will dissolve most of the refractory minerals. Hot water will do it most rapidly: but cold water will do essentially the same, if sufficient time be given. Professors W. B. and R. E. Rogers, in this way dissolved portions of more than thirty rocks and minerals, seemingly the most unyielding, such as feldspar, mica, augite, tourmaline, hornblende, chalcedony, epidote, talc, serpentine, obsidian, lava, greenstone, gneiss, and hornblende slate. It has been probably by means of water chiefly, that the various pseudomorphous processes, which we find to have gone on so extensively in the mineral kingdom, have been accomplished. So great have these changes been, that an able writer (Bischof) says, that "strictly speaking, we do not know with regard to any single mineral, whether it is still in its original condition, or has been more or less altered."

The power of water to penetrate rocks and minerals should be stated in this connection. It not only makes its way into the cracks, fissures, and planes of

stratification and lamination, but also through the mass of most rocks. This it does chiefly through capillary attraction: and few rocks or minerals, long immersed in water, escape its all pervading influence.

By means of these agents of chemical change in the atmosphere and the waters (some others of minor influence might be mentioned), we sometimes find the surface of rocks, to the depth of 10 to 15 feet, so thoroughly disintegrated that they can easily be removed by the shovel. This fact may be observed in many rocky regions south of Pennsylvania. The drift agency further north, has swept off the disintegrated mass, so that in New England we get but a feeble idea of its extent.

In this way are the rocks prepared to be acted upon mechanically by erosive agencies. These too are chiefly water in some form.

3. *Water acts mechanically*, first, as breakers or waves, tides, and oceanic currents. These all act conjointly, for the most part, and it cannot be doubted that nearly all the materials of which the sedimentary rocks, consolidated and unconsolidated, are composed, have been accumulated and deposited by this joint action. To be sure, waves, tides, and currents act with the most important results upon loose detritus: but if we suppose a continent gradually rising or falling, every part of its surface will be brought under the denuding agency; and the projecting naked rocks, subject to the ceaseless action, cannot but yield to its force. Indeed, of all the causes operating to wear down the surface, waves, tides, and currents, have been the most efficient, and have done most to give our present continents their form and outline.

Secondly, as fresh water currents, chiefly in the form of rivers, which drain the land. They would have but little effect upon the rocks were not the latter softened and disintegrated. But loosened materials it can sweep off, and distribute, according to its velocity. And when once it has set detritus in motion, that will tear away projecting fragments, which the water alone could not remove. In some mountain slides, such as that described in my paper on Terraces, as produced on Mount La Fayette, by a powerful shower, the work of erosion accomplished by the water and detritus is almost equal to that of glaciers.

Thirdly, the expansive force of water, when freezing, is one of the mightiest of all known agencies for lifting rocks out of their beds. If water finds its way into cracks and cavities in the rock, and then freezes as solid as we know it may do in northern regions, it will exert a power which even gunpowder could not equal. Thus would the fissures be widened, giving an opportunity for a larger quantity of water to freeze in them the subsequent winter, with a still stronger force and wider effect. Thus, in time, are the most solid and deep-seated masses so heaved out of their original beds, that ice floods, or other agencies convert them into boulders and roll them along the surface.

Fourthly, Glaciers, Icebergs, Ice Floes, and Ice Floods, form agents of erosion of tremendous power. In these cases, blocks of stone, gravel, and sand are frequently frozen into the bottom of the ice, so as to act like enormous rasps upon the surface, over which they move with almost irresistible power. I need not go into details on this subject. For any one who has read the works of arctic and antarctic voyagers in latter times, and the histories of Alpine glaciers, must be impressed

with the energy of these agencies. And whoever has examined the surface of the northern parts of this continent with a geological eye, cannot doubt that he has before him examples of their former operation. If the glacial phenomena that now exist in the northern part of Greenland, as they are described in the works of Dr. Kane, once existed here, they would satisfactorily explain the drift exhibitions of North America.

The ice floods in mountain torrents, above alluded to, possess a power in the removal of detritus, second only to glaciers and ice floes. These several agencies are indeed very similar. For a glacier seems to be only a river of ice urged forward mainly by the force of gravity, aided slightly, perhaps, by the freezing of water in the crevices. I have sometimes seen a mountain stream in New England, crowded with blocks of ice so wedged together, that I have safely walked over its surface; and yet the mass was slowly in motion, and it closely resembled a glacier, even in its erosive power. That of glaciers we know to be still greater; nor can that of large icebergs, when they plough upon the bottom of the ocean, be less, but in some cases it must be greater.

To these agents of erosion, perhaps, I should add those of heat and gravity, and the action of plants and animals upon the rocks. But the first two are implied in the agencies already named; and the two latter are so limited in their action, as hardly to need description in this place.

Conjoined Results of these Agencies.

They have sometimes acted together and sometimes successively upon the same surface: and sometimes the latest action has obliterated the previous ones. But the final results we can trace in the following phenomena.

1. *In the Character of the present Shores of the Ocean.*

This presents two phases. The first consists of the beaches, bars, hooks, and shoals of loose materials which the breakers, tides, and currents, have worn off, sorted, and deposited. In some places the projecting shores of unconsolidated materials have wasted away over a wide surface, while in others the sand-banks have been extended a great distance. The encroachments upon the solid rocks, that project into the waters, is less obvious during the life of man; but in many places it is constant, and, therefore, in the course of ages must be very great.

The other phase of oceanic action, is exhibited in the fiords that are found frequently along the coast. These consist of narrow friths that run up between narrow headlands, as in Sweden and Norway, and along the coast of Maine, in this country. It is easy to see that they have resulted from an alternation of harder and softer strata, on the latter of which the sea has operated more effectually than upon the former, aided sometimes by the drift agency. The extent to which this action has been carried on in many places, is truly surprising, and indicates a vast period of time for its accomplishment. Along the coast of Massachusetts, for instance, where we see that Cape Ann and the rocks of Cohasset consist of unyielding

syenite, while around Boston, they are softer metamorphic slates, we cannot doubt why Boston Harbor has been scooped out by the action of tides and breakers; and probably we would extend the same conclusion to the whole of Massachusetts Bay; although at present Cape Cod is extending in a northeasterly direction, because a current sets in that direction along the coast. In passing from Cape Ann to the Bay of Fundy, some 300 or 400 miles, we find almost the whole coast serrated by fiords, some of them 20 miles long, including the many islands that once constituted continuous ridges.

2. *In the Extensive Denudations of the Strata by Oceanic Agency, when the Surface of Continents sunk beneath, and emerged from, the Waters.*

This has doubtless been the most powerful of all the agencies of erosion which the surface has undergone. In South Wales, where the geology has been examined with almost unequalled thoroughness and accuracy, by the Ordnance Geological Surveyors, Professor Ramsay has made it almost certain, that as much as 10,000 feet in perpendicular thickness has disappeared. I do not think Geological observations in this country have been prosecuted with the minute accuracy requisite to determine the denudation here. From what I have observed, however, it would not seem extravagant to assert, that an equal amount of strata have disappeared from some parts of our country. In my paper on Terraces, I have endeavored to show, that since the tertiary period, the continent has once sunk below the ocean, and once emerged from it. Furthermore, I intend in this paper to point out certain valleys that must have been occupied by rivers before the continent's last submergence. Tracing back its history still further, we may be sure that during the deposition of the coal measures, a large portion of it at least must have been below the waters. Yet previously, or perhaps contemporaneously, large portions of the surface must have been dry land, to nourish the prolific flora which produced the coal. During the Devonian and Silurian periods, we have still clearer evidence that almost the entire continent was covered by the ocean.

We may then be nearly or quite sure of at least three depressions of the North American continent, beneath, and an equal number of elevations above the ocean, since the fossiliferous rocks began to be formed. And, in general, it is clear that these vertical movements were but slightly paroxysmal; so that every part of the surface has been again and again exposed to the long-continued action of waves, tides, and currents. The amount of erosion must have been prodigiously great; and, in my opinion, we find the evidence of it almost everywhere in the mountainous districts of our country. Even where our valleys are so narrow at their lower part, that rivers may well have worn them out, their upper part is so widened that only waves and tides, rushing back and forth between rocky islands, could have caused it. Indeed, the ragged isolated appearance of a large part of our mountains, save on their northern sides, can be explained only on the supposition of having been subject to powerful oceanic action.

Sir Charles Lyell, in connection with Professor John Locke, has made an estimate of the amount of denudation of the rocks above the lower Silurian at Cincin-

nati. It proceeds on the supposition that the Appalachian and Illinois coal fields were once continuous. In that case, the strata at Cincinnati must have been swept off to the depth of about 2000 feet. Plate XII, Fig. 3, copied mainly from Lyell's Travels in the United States, will give an idea of this example. Prof. Locke had promised me a more accurate statement of this case, but his recent death has deprived me of this expected aid. I regret it, because I am aware that some geologists do not place much confidence in this example, as indicating the amount of erosion, and I feel myself unable to form a very decided opinion concerning it. It has every appearance of a plain case, if we can judge from the figure, and Prof. Locke felt quite confident of its reliability.

I will venture to refer to one other example, which, in my estimation, will give some approximate idea of the amount of this work of erosion. It is the part of the Connecticut valley occupied by secondary rocks, especially the part reaching from New Haven to Mettawampe, in Sunderland. It will be seen by Plate III, that this valley is traversed by a few narrow and precipitous ridges, which consist of trap based on sandstone, or rather interposed between its strata, as enormous dykes or beds. Mettawampe and Sugar Loaf, however, are sandstone, and the former rises higher than any mountain of secondary rock in the valley, being 1175 feet above Connecticut river, and 1295 above the ocean. Sugar Loaf is about 500 feet above the river. Plate XII, Fig. 2 is a section crossing the whole valley at this place, from the gneissoid rock of Leverett on the east, to the highly inclined strata of mica slate in the west part of Deerfield. The sandstone, dipping easterly from 5° to 30°, has an unknown depth, and rises to the top of Mettawampe. In passing up the valley from Long Island Sound, this mountain and Sugar Loaf, which is the southern termination of a ridge running north through Deerfield, Greenfield, and Gill, are the first high bluffs of sandstone without trap, with which we meet, and they stand up with almost perpendicular walls, having every appearance of being merely the remnants of a formation that once filled the valley. There is no appearance of any dislocation of the strata, although there does exist, near the base of Mettawampe, a narrow bed of trap, as shown on the section. The valleys east and west (right and left on the section) of Sugar Loaf, exhibit every appearance of having been worn out by water, and it is difficult to avoid the conclusion that the sandstone, at least to the height of Mettawampe, once filled the valley of the Connecticut to Long Island Sound; a distance of nearly 100 miles; and that long exposure to oceanic action has worn the whole away as far as Mettawampe, except where protected by the overlying trap. This latter rock, being excessively hard, has in a great measure resisted these agencies, and now stands out in ridges, whose rounded and furrowed surface indicates long continued powerful erosion. I can assign no possible reason why these trap ridges thus remain, except that the softer sandstone has been worn away, nor can I imagine any other agency which could have accomplished the work, save the ocean. Judging from its effects in other parts of the world, it is not extravagant to conclude that this is sufficient for the mighty work. Nay, the probability is, that even Mettawampe shows us by no means the original elevation of the sandstone. It may have been far greater;

for the top of that mountain shows as distinct marks of erosion as any other portion of the valley.

Under the quaint term of Purgatories, I introduce another evidence of oceanic denudation, which we can connect with operations now going on in some places upon the coast. In several works on geology I have given examples of this peculiar sort of erosion; yet they do not seem to have arrested the attention of geologists, at least under this name. Of the origin of the name I know nothing, but I take it as I find it among the people. Along the coast we find sometimes long and deep chasms in the rocks, into which the waves still rush during storms, and by their concussion wear away the strata and lengthen the gorge. Sometimes this work is aided by the jointed structure of the rock, which produces parallel fissures, and when these are only a few feet apart, they enable the waves to carry on the work of erosion more rapidly. In my Report on the Geology of Massachusetts, I have pointed out two striking examples of these Purgatories, where we see the process actually going on, on the southern shores of Rhode Island. It is no wonder that those who never thought of the manner in which they were produced, should have given the same name to a much larger and longer chasm in the town of Sutton, Mass., far removed from the ocean. I have discovered another at a still greater altitude and further from the ocean, in Great Barrington, Mass. But I have given so full an account of these cases in my report above referred to, that I need only refer to that work. I can imagine no other explanation of their origin that will at all meet the facts, although this has its difficulties.

I will here refer to another example, which, although I have not seen it, I have been led from Dr. Charles Jackson's description to regard as a Purgatory. I refer to the Dixville Notch, in the north part of New Hampshire. Here, through the summit of a mountain of mica slate, which forms the dividing ridge between the Connecticut and Androscoggin rivers, we find a fissure from 600 to 800 feet deep, with nearly perpendicular sides. Its situation forbids the supposition that the gulf can have been produced by fluviatile action, since the streams here run in opposite directions into the Connecticut and Androscoggin. But it is just the situation where the waves of an increasing or retiring ocean would act most powerfully. The chasm may have been once occupied by a trap dyke, as supposed by Prof. Hubbard (*American Journal of Science*, vol. ix. p. 160, N. S.). But my inquiry simply is, how the trap, or other material which once filled it, has been removed. And it seems to me that we must resort to oceanic agency.

I have little doubt that careful examination would discover many more of these "Purgatories" in the mountainous parts of New England. Indeed, what are the famous "Notches" at Franconia and the White Mountains, but examples somewhat modified of the same kind?

3. *Erosions by Drift.*

This agency, as I have endeavored to show in another place, may be regarded as chiefly or entirely ice and water. Yet these causes have operated under such circumstances as to demand a notice distinct from that of the ocean, or of glaciers.

In our country, as well as in northern Europe, the force appears to have had a southern direction. Consequently, the northern sides of our hills and mountains, as well as their tops, are rounded and striated, while their lee side is rough and precipitous.

If any one wished to be impressed with the extent and power of this agency, let him compare the rounded appearance of the mountains and hills of New England, with the pointed and jagged aspect of those of Wales, or the Alps, especially above the line where this agency has operated. He will see that the amount swept away must have been immense; nor will his conviction of the quantity be lessened when he examines the loose detritus covering the surface of northern countries, most of which was originally drift.

4. *Erosions by Rivers.*

To this action I have given more attention than to any other form of erosion. At the outset, however, I found myself embarrassed by the difficulty of distinguishing between river action and the other denuding agencies above described. So far as I know, very few definite rules on this subject have been proposed by geologists. I give the following as the result of my own examinations. They are not in all cases as decisive as I could desire. But they seem to me sufficiently so in general, to enable one to discriminate between the different agencies, and they have led my mind to some interesting conclusions from phenomena which I had hitherto overlooked.

Marks by which River Action can be distinguished from Drift Agency.—1. By the direction in which the denuding force has acted. Since the drift agency in several countries took a southerly course, we may conclude erosions made in other directions to have resulted from rivers. Or more specifically, having determined the course taken by the drift in a given district, we may refer other marks of aqueous action to rivers or the ocean. I ought to make an exception of those few cases where the marks of ancient glaciers have been found in the same countries as the drift phenomena, with which they agree, except that the striæ made by glaciers follow down the valleys in whatever direction they run. In every other respect the glacier marks correspond to those of drift, and can be distinguished from fluviatile action by the marks that follow.

2. Drift agency has eroded the northern slopes of mountains; but rivers have cut channels through the rocks in every direction, or where they have pressed against the sides of hills, they have formed steep precipices.

3. The drift agency has but slightly conformed to the minor irregularities of surface, but has operated like a huge plane, or rasp, to remove protuberances. Whereas rivers have insinuated themselves into the minutest anfractures and cavities, smoothing the uneven surface—the depressions almost as much as the protuberances.

4. Drift agency has covered the eroded surfaces with striæ and furrows of various sizes, from the finest scratches, to troughs several inches deep. But save in a few spots, where ice with gravel frozen into it has been crowded over the surface,

no such markings are the result of river action. The rock is smoothed sometimes almost to a polish, but not distinctly scratched, unless something more than water, or gravel and sand driven by water, has acted upon it.

5. The drift agency sometimes operated in an up-hill direction, even to the height of some hundreds of feet, whereas, rivers can operate only upon a level or upon a descent.

6. Pot-holes in the rocks are produced by rivers where they form cataracts, but never by the drift agency.

7. Where successive layers of rock are superimposed upon one another, some are more easily worn away than others, and usually the central parts of a stratum are the hardest. When currents of water act on such ledges, the edges of the layers will be rounded and interspaces or grooves be produced: not regular, indeed, but more or less deep and wide, according to the greater or less ease with which the strata are disintegrated. But no such effects are produced by drift agency. All parts of the surface, whether harder or softer, are swept down to the same level, or nearly so.

Marks by which to distinguish between Fluviatile and Oceanic Agencies.—This is a much more difficult case than the last, and in some instances, I despair of determining by which of these agencies erosions were produced. In most cases, however, I think the distinguishing marks are clear to a practised eye.

1. Fluviatile action produces pot-holes, when rivers have cataracts, but they never result from the action of oceanic waves, tides, or currents.

2. When chasms or gorges are worn in the rocks by waves and tides, they are usually almost straight, and generally follow the jointed structure of the rock, producing purgatories. But when rivers wear out long chasms, they are usually more or less crooked, as that of the Niagara river, for instance.

3. Rivers have little power to form wide valleys. Sometimes, however, as a stream cuts its bed deeper and deeper, either in consequence of the strata being softer on one of its banks, or of a curvature in its course, it moves laterally so as to leave a sloping bank on one side, perhaps to a great height. In that case, however, the opposite bank will be steep. If both banks slope nearly alike, so much as to make the upper part of the valley quite broad, we must impute much of the erosion to oceanic action; to the flux and reflux of the waters through the opening for ages. The lower and narrower part of the same valley, in such case, may be the result of river action. Or the river may have begun the work at a high level, and it has been subsequently modified by the ocean. I apprehend that most of the valleys in mountainous regions have been produced by this joint agency.

4. If the crest of a mountain is crossed by parallel valleys of different heights, evidently eroded, the presumption is, that the denudation was accomplished mainly by oceanic action; by the flux and reflux waves and tides, aided, perhaps, by icebergs, during the upheaval of the land. For though a river, in such a case, might sometimes change its bed, so as to wear each successive one deeper and deeper, the supposition would imply that the successive beds had originally nearly the same relative depth, and it is not easy to see why a lake should have so many outlets at the same time. Lakes do, indeed, sometimes have two outlets, at oppo-

site extremities; but I do not recollect a case in which their drainage is effected by several parallel outlets.

A case to illustrate this principle occurs in the valley of Connecticut river. The trap range, called Holyoke and Tom (see Plate III), crosses that valley, or nearly so, obliquely; its northern extremity (Holyoke and Norwottuck), turning across the valley almost at right angles. Its crest is crossed by numerous valleys of erosion, of very unequal depth, in one of which Connecticut river now runs. I have no doubt that the drift agency has had a good deal to do with their erosion, yet such is the situation of these valleys, that when the ocean gradually receded from the surface, the waves and tides must have acted with great force in the manner above described. During the last depression of this region below the ocean, the drift agency probably swept over the ridge and modified the small valleys; but probably the ocean did most of the work long before. I should go more into detail in respect to this case, had I not already done so in my Report on the Geology of Massachusetts, and in my Elementary Geology. I have not, however, in those works advanced the above hypotheses to account for the denudation, but have merely inferred that water and ice must have been the agents.

5. If the face of a mountain be steep and show marks of denudation; if it be an outlier; that is, have no corresponding eminence opposite, so as to form a valley, and if there be no evidence of a dislocation of the strata, we must impute the erosion to oceanic agency; since fluviatile agency is out of the question. But if, while the continent was sinking or rising, its waves and currents beat against the mountain, it might so wear away the strata as to leave a mural face. In this case, however, we must suppose a previous inequality of surface, so as to enable the waves to act upon the shore.

6. The main force of the ocean is directed towards the axis of mountain chains, although tides and currents will be parallel thereto. Hence the eroded valleys will run towards the crest of the mountain chain. If, therefore, we find valleys running very much oblique to the axis, we may presume them to be formed by rivers. It must be remembered, however, that the direction of the strata will greatly modify the direction of erosions, as in the case of fiords. The unequal hardness of the strata, also, will operate in the same way: so that the application of this distinctive mark will require caution.

7. In a few cases, where a river has worn a passage through a mountain ridge, and at the same time has, from time to time, made lateral changes in its bed, it might leave a succession of precipices, which were its former banks, on one side, while on the other, they might be worn away. In such a case, however, we must suppose that the stream, after excavating a bed, should suddenly desert it; else, if the lateral change were slow and equable, it would leave on the deserted side, only a uniform slope.

In suggesting this distinction, I have had a particular case in view, which I will shortly describe; but about which I am in doubt, whether to refer it to oceanic or fluviatile action, or to both united.

Modes and Extent of Erosion by Rivers.—1. The manner in which rivers are formed, as a continent rises from the ocean, has been described in my paper on

Terraces. During the rise of the land, the water would remain only over its depressed portions, and it might be that the lakes or ponds thus formed, if ranged along some extended depression of surface, would constitute a chain of lakes. The water poured into them from the neighboring hills, would produce an oceanward current, and this, passing through the barriers of the lakes, would begin to wear them away. This would be the first step towards a river.

2. The above processes continuing to go on, the lakes would become narrower and the barriers be more deeply eroded, so that what we call a river would be the result. The matter, however, which was worn away at the barriers would in part be deposited in the deeper and more quiet water between them; and in part be carried forward to the ocean. Hence the process would be one both of erosion and of filling up.

3. That, upon the whole, the process of excavation exceeds that of filling up, will be evident from the following facts:—

1. The increase in the deltas of rivers.

The Merrimack sends forward, annually, about 839,171 tons of sediment to increase its delta at Newburyport.

The Ganges pours into the ocean, each year, 355,361,464 tons of mud.

The Mississippi carries forward 28,188,383,892 cubic feet, or one cubic mile in five years and eighty-one days. Its whole delta contains 2720 cubic miles: and, therefore, at the rate above indicated, 14,204 years would have been requisite to form it.

But such examples need not be multiplied, for every river tells the same story. The amount of sediment at its debouchure is ever increasing, and, therefore, its bed must be continually widening and deepening.

2. Some portions of the banks of most rivers are composed of loose materials, which form precipitous walls, and thus make it almost certain that the depression now occupied by the river, was once occupied by the same sort of materials as the banks, which the waters have carried away.

3. Wherever rivers run through rocky gorges, especially if cataracts exist, we find distinct evidence, in the worn appearance of the rocky banks, and sometimes by pot-holes, that the stream once ran at a higher level than at present, as at the Great Falls, on the Potomac, near Washington: at the Falls on Genesee river, at Portage, and on the Mohawk, at Trenton, New York: on the Connecticut river, at Bellows Falls, New Hampshire. If the surface of the rock, however, has been exposed for a very long time, the atmosphere and frost are very apt to cause it to scale off so as to obliterate traces of river action.

4. The modes in which rivers excavate their beds has been already given, essentially, in describing the effects of water and ice upon the rocks. They are briefly as follows:—

1. By solution of the agents of chemical change.

2. By direct solution of the constituents of rocks.

3. By urging forward loose materials, such as sand, gravel, and boulders, over the surface. When a gyratory motion is produced in the water, the eroding materials produce pot-holes.

4. By entering the fissures of rocks and freezing, so as to separate them by expansion. This is one of the most powerful modes in which the work of excavations is carried forward.

5. By ice floods. In these cases the stream becomes choked with ice, with only water enough to make it plastic, and enable gravity to urge it forward. The moving mass does, indeed, very strikingly resemble a glacier, and it moves forward with a similar immense power; ploughing up the loose surface, tearing off the projecting rocks, and sometimes forming new channels for the river.

6. Where there are cataracts in rivers, all these modes of erosion usually act with a maximum intensity: and at this day probably the principal amount of erosion by rivers takes place where there are cataracts. These cataracts are constantly receding, although when measured by the life of man, the rate of retrocession is scarcely perceptible; but measured by geological periods, it becomes very manifest, and we find evidence, that in this manner long and deep gorges have been produced, and lofty barriers removed. The consequence of this latter process is, that the river below and above the barrier, thus partially or wholly removed, will excavate a deeper bed in the loose materials there accumulated.

5. Without attempting to determine the precise amount of erosion by rivers, I wish to state distinctly that I do not impute to this agency the whole, or even the larger part, of the formation of the valleys through which rivers now run. Much less do I maintain that present rivers have produced these valleys: for there is proof in some cases, that other streams once flowed through valleys now occupied, perhaps, by rivers totally unable to have eroded them. For the formation of most of our present valleys we may assign the following agencies:—

1. The original upheaval and dislocation of the strata.
2. Long continued oceanic action.
3. The drift agency.
4. Rivers on former continents.
5. Existing rivers.

I impute to rivers only such a part in the work of erosion as can be proved by an application of the preceding principles.

Caution in the application of the preceding Rules.—1. The older the rock through which rivers have cut their way (*cæteris paribus*), the greater should we expect the amount of erosion.

2. But, secondly, the position of the strata, if the rock be stratified, and the amount of water acting upon them, or the number and direction of the fissures, if the rock be unstratified, will greatly modify the amount of erosion. If the strata cross the stream and dip in the same direction as the slope of the river, the action of the water will be much more powerful than if the dip is in the opposite direction. Or if the inclination of the strata corresponds with that of the stream, the erosion will obviously be slower. Again, some unstratified rocks present but few fissures, while others are full of them, and this fact will make a great difference in the erosion.

3. Rocks, essentially alike in chemical composition, may yet vary very much in hardness, and in the ease with which they might be disintegrated. How great

the difference is, for example, between chalk and Silurian limestone, especially when a small proportion of silex enters into the composition of the latter. Certain kinds of syenite disintegrate with great ease, compared with common trap: yet both are composed of feldspar and hornblende.

4. Rocks, essentially alike, may yet be decomposed with very different degrees of facility, on account of the presence in some of them of such minerals as carbonate or sulphuret of iron or manganese in some form. It is surprising sometimes to see to what depth the whole character of the rock will be changed, and how it will be disaggregated, so that aqueous agency can easily denude its surface.

Detail of Facts.

Guided by the preceding principles, I have made a collection of examples, which I suppose to be cases of erosion mainly by rivers. In some of them, however, other agencies have been largely concerned, perhaps more largely than the rivers. I have not confined myself to examples founded on personal observation, and of course, in those cases which I have not seen, I feel less confidence than in the others; for careful examination is sometimes necessary to decide certainly whether river agency has produced the gorges. Yet by observing the characters of those erosions, which personal examination refers with great confidence to river action, we can with great probability refer other cases to the same cause, which we have only seen described by travellers or geographers.

The first example below, is not one of the most satisfactory; yet as it is the case which first called my attention to the subject, I shall describe it with more detail than usual.

I cannot doubt that a more extensive examination than my time will allow of the works of travellers and geographers would enable me easily to double the following list. Still, as travellers usually describe such scenery only in general terms, the geologist can but seldom decide certainly what cases are examples of erosion by rivers.

So far as it is in my power, I shall describe these erosions under the head of the different rocks in which they exist.

1. *Erosions in the Hypozoic or older Crystalline Rocks, such as Gneiss, Mica Slate, Talcose Slate, &c.*

a. In Buckland, on Deerfield River, a little west of Shelburne Falls.

A ridge of gneiss and hornblende slate lies west of the village of Shelburne Falls, through which Deerfield river has cut a passage. On the road from that village to Charlemont, where it crosses this ridge, we meet with pot-holes in the ledges of gneiss; and, indeed, the road occupies an old bed of the river. These pot-holes are 80 feet above the present bed of the stream, and the terrace materials rise to that height on the north side of the river. This proves that the stream was once dammed up to that height, else the pebbles and sand could not have been sorted

and deposited. Such a rise must have thrown the waters over a basin which extends several miles into Charlemont, as shown on Plate IV. The old river bed is marked on that map, as well as the present course of the stream. It is clear, then, that since the deposition of these terrace materials, the river has not only changed its course a considerable distance to the north, but has cut a new channel 80 feet deep, through very hard gneiss rock. It was probably the blocking up of the old river bed by the gravel deposited while the waters stood over the spot, that caused the river to change its course. The evidence on which such an explanation rests, is not quite as striking at this spot as at some others of a similar character to be subsequently described, and, therefore, I will not dwell upon it. But if admitted, it shows us *the amount of erosion by the river, in very hard rock, since the deposition of the gorge terrace on its bank.* And since the terrace lies above the drift, we are sure that so much work at least has been done by the river since the drift period. Nay, after that period, the materials of the terrace at the gorge must have been very slowly accumulated, so that this erosion of 80 feet may not carry us more than half way to the period of the drift.

At the top of Plate IV, is a section of the mountain through which Deerfield river has cut a passage, as above described: it runs in the direction of the axis of the mountain; that is, nearly north and south. On the north side of the river the mountain rises to the height of more than 1800 feet above the ocean, and forms Mount Pocomtuck (formerly Walnut Hill). On the south the ridge ascends rather rapidly, till within half a mile it has reached the height of 545 feet above the present river bed. Then it descends 218 feet, into a valley now covered with gravel and boulders, looking like a former river bed. Then the ridge rises for several miles and attains a height nearly equal to Pocomtuck.

Having ascertained the action of the river 86 feet above its present bed, as proved by the pot-holes, I was led to inquire whether any marks of its erosions existed at a higher level, towards the south. I found that the north slope of the hill exhibited a succession of ragged walls for a considerable height, as shown on the section connected with Plate IV. These have the appearance of successive banks of the river, as it stood at different elevations. These walls present a curve horizontally, whose convex side is towards the northeast, which would be exactly the effect of the river sweeping around towards the southeast in a curve of that description, as it must do to correspond with its present course. (See Map.)

At first I felt very little doubt that these facts were decisive proof of the former action of this river, at least to the height of 545 feet above its present bed. But some doubts as to this point have been subsequently excited. If the river wore down the whole of this gulf by a slow and uniform action, I can hardly see why the south bank should not have a uniform slope instead of several steps. Nor do I see any reason why it should have changed its bed so many times suddenly, unless we suppose such a state of things to have existed at each lateral movement, as at the last—that is, a filling up of the old bed by loose materials, because the region had subsided beneath the ocean. This would suppose more vertical movements than have generally been admitted. Again, if the sea once, or more than once, stood over this spot, we should expect that the flux and reflux of the waves

through the depression in the crest of the mountain, which may have existed, would wear it away, as we now find it. After all, however, water flowing in the same direction as the present river, affords a more natural explanation of the erosions at this spot than any other supposition; and I apprehend that they may have been the result of both kinds of agency: for when a mountainous region, like the one under consideration, is either gradually sinking beneath, or rising above, the ocean, what is at first an ocean, becomes an estuary, and then a river.

The Ghor[1] is a deep narrow valley, extending from Shelburne Falls to Deerfield Meadows, about eight miles. Throughout most of this distance the stream flows obliquely across the hard strata of mica slate and gneiss, which have a high dip in the same direction as the slope of the stream. The rocks crowd so closely upon the river, and rise so precipitously for several hundred feet, that no attempt has ever been made to make a road parallel to the stream, and only in one place is it crossed by a road, and there with difficulty. Near the upper extremity of this valley we find Shelburne Falls, whose height I know not: but there we see the effect of the cataract upon the hard and almost unstratified gneiss rock, in the formation of pot-holes of enormous size, some of them being as much as twenty feet deep, and eight or ten in diameter. There, too, we see the effect of the expansion of freezing water in the fissures, in the removal of huge blocks from their native beds; so that upon the whole we cannot doubt that the cataract is receding. Nor can the geologist doubt that it may have receded the whole distance of eight miles from Deerfield Meadows. Nay, perhaps previous cataracts at higher levels, may, in like manner, have worn backwards, so as to form the whole of this Ghor. Its situation is such, and it is so crooked, that it seems difficult to suppose the sea to have had much to do with its excavation, except, perhaps, to widen its upper part.

b. Ancient River Bed at the Summit Level of the Northern Railroad in New Hampshire.

On Map No. 1, a mountain ridge is represented as running from Connecticut river, at Bellows Falls, northeasterly to the White Mountains. No such distinct mountain exists there: but it marks the dividing ridge between Connecticut and Merrimack rivers. The valley of the latter is about 150 feet lower than that of the former. Through this dividing ridge I know of not more than four depressions of considerable depth. One of them is in the town of Orange, on the Northern Railroad, and is 682 feet above the Connecticut, at Lebanon, and 830 feet above the Merrimack. Another is at Whitfield, on the White Mountain Rail-

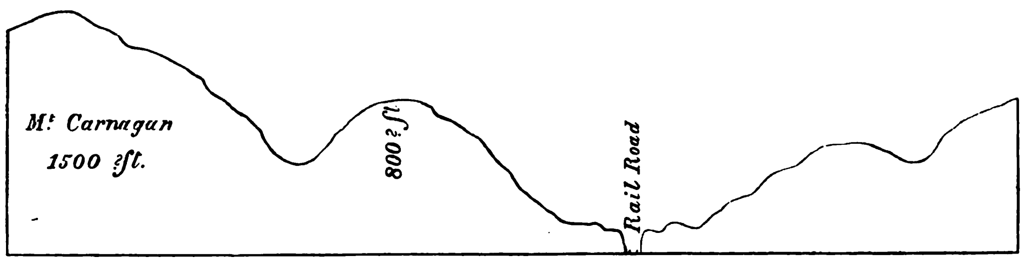
[1] The Geological Class in Amherst College, a few years ago, having forced their way on foot through this wild and difficult gully, seldom trodden by man, felt at liberty to propose for it the Arabic name of *Ghor;* which may be used till a better one is suggested. In like manner, the class that graduated in 1856, visited Walnut Hill, referred to in the text, and imposed upon it by ceremonies, the name of Mount *Pocomtuck;* the Indian name for Deerfield river, which washes its southern base.

road, and is 650 feet above the Connecticut. The third is the Franconia Notch, which is about 2295 feet above the same river. And a fourth is the White Mountain Notch, which is 1557 feet above.

On the west side of Connecticut river we find the lofty Green Mountain range, running parallel to the river, its culmination being some 30 miles distant. Through this ridge there are two depressions occupied by railroads. The Rutland and Burlington road crosses at the Mount Holly Gap, 1350 feet above Connecticut river, at Bellows Falls. The Central Railroad passes the summit, near Montpelier, 930 feet above the Connecticut, at Lebanon. Still further north, the Passumpsic and Connecticut Railroad (not yet finished) passes over the summit at about 900 feet above the Connecticut at West Lebanon.

At Bellows Falls, the hills extending easterly and westerly to these two lofty dividing ridges, crowd so closely upon the Connecticut as to leave only a narrow gorge, although the mountain on the east side of the river (Kilburn Peak, formerly Fall Mountain,[1] 828 feet above the top of the falls and 1114 feet above the ocean) is the highest. Yet if this gap were closed, it would raise the waters high enough to flow out laterally through some of the passes above mentioned as the location of railroads. And when we see the evidence of erosion on the west face of Kilburn Peak, to the height of 900 feet, we cannot but suspect that this gap was once closed, and that the waters did spread out so as to form a lake, extending to the dividing ridges east and west, and northwards perhaps even to Canada. If, therefore, we could find evidence of the former passage of water through some of the above named gaps, it would make such a conjecture almost certain. Such evidence we do find at the Summit level of the Northern railroad, in Union, two and a half miles from the station house in Canaan.

In approaching this spot by railroad from Connecticut river, we ascend a small tributary to Canaan. There we have before us a mountain ridge, running nearly N. E. and S. W., with a deep depression in Union. To the north, as a part of the ridge, lies Mount Carnagan, which I judged to be at least 1500 feet above the railroad. The cut below will give some idea of the appearance of the range as we approach it from the west. The stream has diminished to a small brook, which



[1] In 1856 the Class in Amherst College, that will graduate in 1857, visited Fall Mountain, and formally imposed on it the name of *Kilburn Peak;* to commemorate the memory of two men by the name of Kilburn and Peak, who, with their families, the earliest settlers of Walpole, performed a feat of courage and self-defence at the foot of this mountain, perhaps more daring and extraordinary than the whole history of Indian warfare in this country can present, and rivalling that of Leonidas and his Spartans, at Thermopylæ.—See *New Hampshire Historical Collections.*

has its origin in a peat swamp, that lies immediately to the west of the highest part of the gorge. Not long before we reach the cut for the railroad, we pass one or two long ridges of sand and gravel, running N. W. and S. E., and resembling very much genuine *osars,* and I have marked them as such on the map. The rock is gneiss, traversed by large veins of coarse granite and feldspar, trap and quartz. The artificial cut is 30 feet deep and 1200 feet long; and along it, near the east part of the ridge, are seen the remains of several pot-holes. In short, there is the most conclusive proof that a cataract once existed here, and that the waters ran from the Connecticut into the Merrimack valley. For on the west side of the ridge occur very distinct marks of drift agency from N. W. to S. E., and this would have obliterated the river action had it been on that side; as it would have been, had the current passed from S. E. to N. W. At present, on the Merrimack side of the ridge, is a peat swamp, from which a small brook issues towards the east.

The conclusion from these facts seems irresistible, that the valley of the Connecticut was once filled with water to the height of 682 feet above its present bed, and that here was one of its outlets. Over the whole of the valley, for many rods to the right and left of the railroad, we see marks of very powerful aqueous action, nearly obliterated, indeed, in some places by the drift agency, but still manifest to a practised eye. But it is clear that the water poured through this outlet before the drift period; consequently it was on a former continent, the one that was submerged at the drift period. During that last submergence, the pebbles and sand, still found so abundantly on either side of the ridge, and even beneath the peat in the very gorge, were deposited.

In looking at this outlet of a lake of a former continent, one cannot doubt that a great amount of erosions has here taken place. The great width of the openings in the ridge, would indicate the action of waves and oceanic currents, but that the waters of the lake itself did much of the work, can hardly be doubted.

2. *Gorge at Bellows Falls.*—The preceding facts and reasoning make the conclusion almost irresistible, that the gap at Bellows Falls, through which Connecticut river now runs, was once closed, at least to the height of 682 feet, with the addition of the fall in the river between Lebanon and that place, say 40 feet, which gives 722 feet. There was probably another outlet to the lake at that height, and perhaps the reason why the one at Bellows Falls sunk faster than that in Union lies in the character of the rock in the two localities; that at Bellows Falls being more slaty and more full of fissures.

At Bellows Falls, as well as at Union, we have evidence that nearly the whole of the erosions was accomplished previous to the drift period. For at the top of the falls, that is, in the bottom of the valley, we find very beautiful examples of striæ and *roches moutonnees,* while only a few rods or feet below them, are fine illustrations of river action upon the rocky banks of the stream about the falls. We are certain, then, that the gorge was mostly excavated previous to the drift period, and we may put the work at least as far back as the period of dry land, which preceded the last submergence of the continent.

I once scaled the almost perpendicular face of Kilburn Peak, on the east bank

of the stream, to see if I could not discover marks of former fluviatile action on its face. Perhaps I ought to have concluded that drift agency had obliterated all traces of river action. But I had noticed that bottoms of valleys have been more affected by that agency than high mural points. Accordingly, on the face of this mountain, I found much less of drift action than at its base: and I fancied that in many places, especially in depressions of the surface, I could see the smoothing and rounding effects so peculiar to running water. In general, however, long exposure to atmospheric agencies has caused a scale to fall off from the surface, and thus nearly destroyed its original character. But even in that case, the general contour might not be destroyed, and thus we may sometimes detect river action where the surface has become rough.

But it is at the top of Kilburn Peak I think the marks of ancient currents of water are most obvious. Here we sometimes see what seem to have been the shores of ancient currents: namely, ragged walls running out in the direction of the valley, that is north and south, but inclining to N. E. and S. W., as if the outlet of the lake, in those early times, had that direction, because certain joints in the rocks have the same, and thus made the erosion easier. But though the marks of ancient fluviatile action on the west side and top of this mountain seemed to me quite distinct, I do not forget how difficult it is to distinguish such action from that of the ocean. But that the river itself was the chief agent in forming this gorge of 800 feet high, I cannot doubt.

3. *Gorge at Brattleborough.*—Wantastoguit mountain, at Brattleborough, 1050 feet above the river, according to my measurements, corresponds in position and shape so nearly to Kilburn Peak, and there is such a general resemblance between the narrow valley of Brattleborough and that of Bellows Falls, that we can hardly doubt that the agencies which operated in the one place acted in the other. I found on the west face and top of Wantastoguit mountain, quite as distinct marks of erosion by water as on Kilburn Peak, on the top perhaps a little more distinct; especially if we admit that the gulfs running N. N. E. and S. S. W., with ragged mural faces, were caused by water from the ancient lake. Perhaps, however, in the less elevation of the hills on the west side of Connecticut river, at Brattleborough, for several miles, we have stronger evidence of oceanic action. But I cannot doubt, that though we have no cataract in the river at Brattleborough, as at Bellows Falls, the stream has had an important agency in past ages and on a former continent, in the removal of a barrier, which once dammed up the Connecticut at this place, and formed a lake reaching to Bellows Falls. That barrier may, indeed, have extended a considerable part of the distance to Bellows Falls, as the narrow and deep gulf reaching even beyond Putney testifies.

4. *Gorge between Mettawampe and Sugar Loaf at Sunderland.*—In another part of this paper I have referred the erosions of most of this valley to oceanic action, though I cannot doubt that the river exercised an important agency. How much, it is impossible now to say: since like the gorge at Bellows Falls and Brattleborough, the erosion was previous to the drift period.

5. *Gorge between Holyoke and Tom, at South Hadley.*—The same remarks will

apply to the passage cut through the trap at this place, as were made in relation to that at Sunderland.

The two last examples, being the one in sandstone and the other in trap, would more logically be described in another part of this paper, but it seemed most natural in passing down the Connecticut to notice the gorges consecutively.

6. *Gulf between Middletown and the mouth of Connecticut river.*—As you pass through this gulf in a steamboat, and see how, in many places, the high and rocky banks crowd down upon the river, and even jut into it, you cannot resist the conviction that the stream itself, or one of a similar character on a former continent, must have had much to do with its erosion. You cannot believe either that it is a gorge produced solely by original folding of the strata, or by oceanic action. It is too long, say about 20 miles, and probably I might add, too crooked, to admit a sufficient force of waves and tides to accomplish the work. However it is not one of the most decided and certain examples of fluviatile erosion.

7. *Ravine through which Agawam river flows, extending from Mount Tekoa, where the river debouches into the valley of Connecticut river, nearly to the summit level of the Western railroad, along the main branch of the river, about twenty-five miles.*—If we were to follow up any other branch of this river, we should find similar ravines. The main one under consideration crosses the strata often at right angles, and there is no evidence of their dislocation on either side; hence its erosion may reasonably be imputed to the river, or the ocean. It is deeper in many places than the Ghor, on Deerfield river, and there are at least two cataracts along its course of considerable height, where the work of erosion is going on. In most places, however, it is wider than the Ghor, admitting of farms and villages. There is scarcely any part of it that presents walls of rock so obviously eroded as at Tekoa, where the river emerges into the alluvial plain of Westfield.

From the fact that an enormous vein of granite is seen in the bed of Agawam river in several places, as at Salmon Falls, I have suggested in my Final Report on the geology of Massachusetts, p. 691, that it might once have extended through a great portion of this ravine; and if so, that it gives the reason why the river chose this track: because such a vein would be more easily worn away than the mica slate. I still think that in this way we may account for a part of the erosion: but I have not found the evidence that the vein occurs through any considerable portion of the river's course.

8. *Ancient bed of Agawam river in Russell.*—This is a well marked example, lying immediately north of the railroad station in Russell. Standing at that spot, and looking north, you have before you a rocky hill, several hundred feet high, on the right or east side of which the river and the railroad now run. But on the left side, the common road passes through a valley about as wide as the river, and filled to a considerable height with terrace materials, gravel and coarse sand, at the north end, but finer towards the south. Near the north end the road attains an elevation above the present river a few rods further north of 74 feet. This is the present height, or nearly so, of the old bed of the river above the existing stream. But upon both sides of the old bed, the steep hills are fringed with the remnants of a former terrace, rising 208 feet above the river; and this doubtless filled the

old bed entirely, but was subsequently worn away, not by Westfield river, but by less powerful agencies. During the last submergence of the continent, doubtless the former bed of the river became filled to the height of 208 feet, so that upon its emergence, the river found a lower channel on the east side of the hill, where it has cut the deep rocky channel in which it now runs. At the north end of this gorge (which is not far from a mile long), and only a few rods north of the Russell depot, we find pot-holes on the west bank, nearly 70 feet above the stream. The rock is mica slate, traversed by huge granite veins. The greatest sceptic could not doubt, after visiting this spot, that the river has lowered its channel at least 70 feet, and admitting this, what reasonable man can suppose that the work has not been carried on at least to the height of 208 feet. The evidence that the river once ran in the old channel is so strong, that the farmers who live in the vicinity, have no doubt of the fact, though unconscious of the interesting geological conclusions resulting from it. For they see the proof in the water-worn appearance of the rocky sides of the old bed, and in the fact that they find logs in the alluvial deposit to the depth of nearly 30 feet.

This then is a case of postdiluvian gorge, in a convenient situation for examination, since the Western railroad passes over it, and a delay from one train to another, would afford time for the exploration. The length of the gorge is not, indeed, as long as from Niagara Falls to Ontario; but the rock here is much more difficult to wear away. A tolerable idea of this case may be obtained from Plate III.

9. *Another old bed occurs on this same river*, or perhaps I should say on its principal or eastern branch, where it unites with the western branch, at Chester village. It lies a little east of the village, is perhaps a mile long, and is separated from the present bed of the river by a hill, perhaps 500 feet high.

10. Still further up this east branch, say about four miles above Chester village, in Norwich, on the east side of the present stream, and separated from it by a hill of some height, is a deserted bed, which may be half a mile long. A small village occurs at the spot, and though I have not made accurate measurements either at this old bed, or at that described in the last paragraph, they both appeared to me to be examples of antediluvial channels through which the river ran on the last continent.

11. *Gorge on Little river, in Russell and Blanford.*—Little river is a tributary of Westfield or Agawam river, into which it empties a little east of the village in Westfield, after having pursued a nearly parallel course through Blanford, Russell, and Westfield. Five miles west of Westfield village, it emerges from the mountains, that bound the west side of Connecticut valley. From this point, for six or seven miles up the river, we find it with occasional interruptions, occupying the bottom of a deep and crooked gorge, so difficult to be crossed that rarely do we find a road over it, nor do any roads lead along the banks near the gorge.

The road to Russell from Westfield ascends the mountain on the north side of the gorge, and here I observed two or three quite interesting facts. By the roadside, perhaps 150 feet above the river, are most distinct marks upon the rocks of the former action of the river. The surface is rounded and smoothed, just as we

often see near falls. I was interested to see how high this fluviatile action might be traced, and found it to grow fainter and fainter as I ascended, but I thought it quite distinct 300 feet above the river (aneroid). It is I think the best example that I ever saw of the gradual disappearance of these marks upwards.

At this spot as we rise above the marks of river action, we meet with what I have regarded as traces of ancient glaciers. These have already been noticed in Part I, on Surface Geology, and will be fully described in Part III, on the Marks of Ancient Glaciers.

I have not ascertained the precise length of this gorge on Little river, though I presume it is six or seven miles, with some interruptions, and three or four miles in its lower part without interruptions, by wider openings. Though the hills that bound the gulf are of very unequal height, yet I think we cannot regard their average height as more than 600 to 800 feet. It reminded me of the Ghor in Deerfield river. It is too crooked to impute much of its erosion to the ocean, though doubtless its upper part may have been widened by that agency.

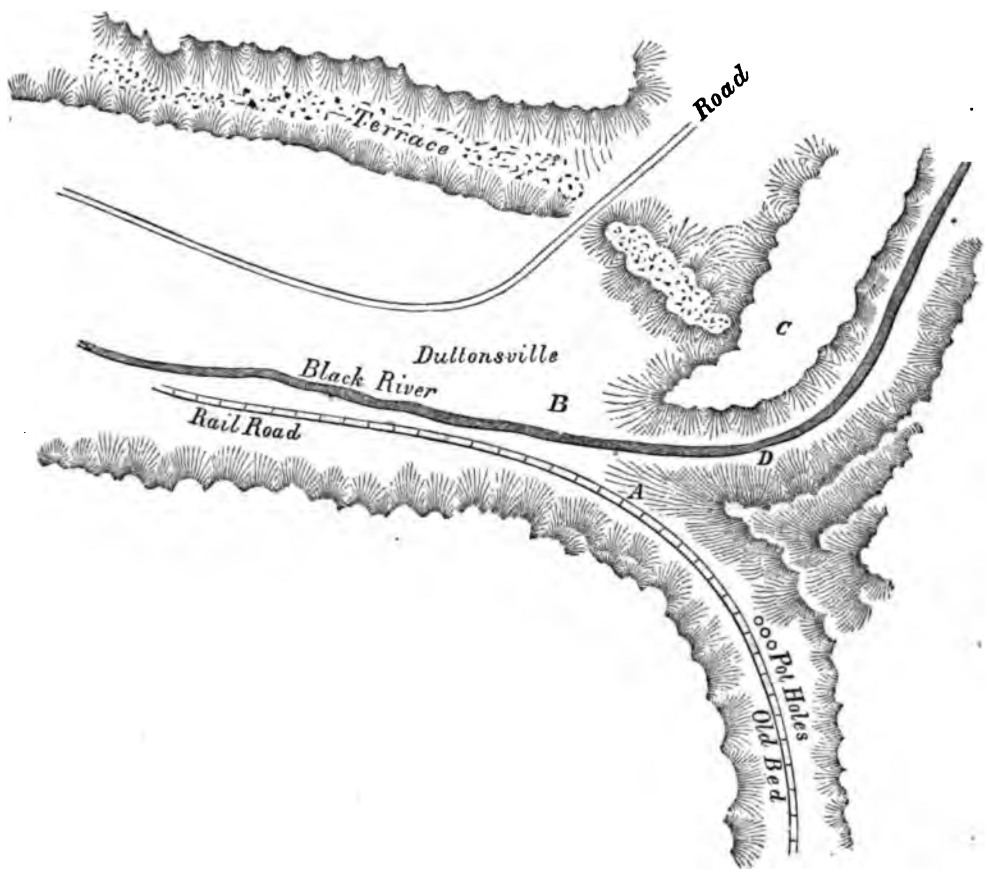
12. *Ancient river beds in Cavendish, Vermont.*—Williams river and Black river, streams of nearly the same size, rise in the Green Mountains, and running nearly parallel, empty into Connecticut river; the former, two or three miles north of Bellows Falls, and the latter, ten or eleven miles further north. Through most of their course they are separated by mountains, rising sometimes, to near a thousand feet in height. Yet there are at least two gulfs, the Duttonsville one and that at Proctorsville, in Cavendish, connecting the valleys of the two streams, and through which Black river once flowed into Williams river: in other words, it is probable that Black river was once a tributary of Williams river. The evidence of the position I shall now present.[1]

The Duttonsville Gulf.

The Rutland and Burlington railroad passes up Williams river from Bellows Falls 18 miles to Gassett's station. There it turns to the right and crosses to Black river, through the Duttonsville gulf. Through its whole course that gulf bears evidence, to a practised eye, of being the former bed of a river, but just before we reach Duttonsville, we find deep pot-holes in the gneiss rock, perhaps 50 feet above Black river. This old river bed, especially near Duttonsville, is choked up to the depth of several feet by terrace materials, which must have been deposited during the last submergence of the continent beneath the ocean. These formed a bank so high, that as the surface emerged, and a river began to run down

[1] I am much indebted to William F. Hall, Esq., now of Washington city, and to Hon. William Henry, of Bellows Falls, for calling my attention to these cases. To the latter gentleman I am, also, indebted for a free ticket on the Rutland and Burlington railroad on a visit to the spot. Nor is this the only time in which I have been thus liberally treated by gentlemen connected with that railroad. Indeed, it is but justice to say, that in no other part of this country have I found all classes of the community so ready to appreciate the connection between scientific researches and the public welfare, and so ready to help them forward, as in Vermont.

the valley, it was turned to the left and found a new channel to the left of the mountain lying east of Duttonsville. On Plate III a sketch of the region is laid down, which will give some idea of the ancient and present courses of Black river. But the published map of that region is so imperfect, that the following sketch, taken by the eye, will probably present a better outline in part.



During the drainage of the country a pond would occupy the basin B, at Duttonsville, extending up the river as far as Proctorsville and perhaps even to Ludlow, and the water would find an outlet at the lowest point. On the north side it was kept in by a gravel terrace, extending to the rocky hill C, and as stated above, the old bed at A was raised by a similar deposit. The result was, that the rocky ridge at D, was the lowest point, and there the stream flowed over and commenced its erosion of the strata. That work has gone on till a gorge has been worn back half or three-quarters of a mile, and the work is now progressing in the hard gneiss rock. According to my barometrical measurements the river falls in this whole distance as many as 183 feet.

As may be seen in Plate III, the old river bed, after continuing, about three miles, towards Gassett's railroad station, forsakes the railroad track, and finds its way to the present bed of Black river some seven or eight miles below Duttonsville. But a similar bed is represented as continuing as far as the Gassett station. No pot-holes, indeed, occur along this ravine, but we cannot doubt that a stream

once flowed through it, and joined Williams river. Indeed, its bottom is only a few feet higher than that of the ravine just described, which branches from it to the left. Yet since the stream must have flowed through the lowest valley at the latest period, we must regard the valley running to Gassett's as the bed of a river at an earlier date. But this subject will be referred to more at length in a subsequent paragraph.

The Proctorsville Gulf.

The bed of the ancient river at Duttonsville is 675 feet above the top of Bellows Falls. Passing from this place two miles up the Black river, we find a rather broad valley almost level, as far as Proctorsville, another flourishing village. Running nearly south from this village, we find a deep narrow ravine, cutting through the high mountain and opening at its southern extremity into the valley of a tributary of Williams river. I found no pot-holes in the sides of this ravine, but every other mark of a former current of water, which wore out the gorge in fact, is seen on the surface. The highest point in the gulf, perhaps a mile south of Proctorsville, is 117 feet above the old river bed at Duttonsville, or 792 feet above the top of Bellows Falls. At the summit the gorge shows a deposit of terrace materials, how deep I cannot say. But the fact is sufficient to show that no stream has passed through the gorge since the last emergence of the continent. But that Black river—or rather the *progenitor* of that river, on a former continent—once passed through this gorge, and was in fact a part of Williams river, will be obvious by an inspection of the rough outline on Plate III. But at what period of antediluvian history did this take place?

If the principle above alluded to be true, viz., that where more than one lateral ravine, once the beds of rivers, open from a common valley, that which is the lowest was last occupied by the stream, then the Duttonsville gulf is more recent than the Proctorsville gulf. I have inferred that the former was the bed of a stream on the continent which immediately preceded the present. Was the latter worn out during the same period; or might it have been the work of a stream on a still earlier continent, that is, the second one anterior to the present? If we knew the depth of the detritus at the summit of the Proctorsville gulf, it might aid in deciding this point. But I can hardly believe that its depth equals the difference of level between the two gulfs. If not, then the Proctorsville gulf must have been higher than the other, during the period of emergence previous to the present. The country below Proctorsville, also, must have been blocked up high enough to throw the waters through the Proctorsville outlet. The amount of erosion since that time, on such a supposition, must have been enormous to bring the region below Duttonsville into its present state. And it would not be an improbable supposition, that the Proctorsville gulf, as well as the right hand branch of the Duttonsville gulf, already described, may have been the bed of a stream on a continent earlier than the last. But I despair of being able to prove this decidedly by any facts within the reach of present observation. And yet those detailed above, do appear to me to prove at least a great difference in the ages of these two gulfs. But whether the period between them embraced a sub-

mergence of the continent, is another question. To be able to trace back with clearness erosions accomplished on even the last continent, is more than I ever expected to be able to do. The above facts come nearer to extending our vision across another mighty chasm, and witnessing events in surface geology upon a still earlier continent, than any I have ever met with. But whether this be a problem resolvable by the geologist I am in doubt.

It is only recently that this subject of distinguishing between postdiluvian and antediluvian river beds has arrested my attention. And from the number of cases that have already fallen under my observation, I cannot doubt that they are quite frequent. I have some other examples to which I shall refer on a subsequent page.

13. *Gorge at Great Falls on the Potomac, twelve miles west of Washington city.*—

The top of these falls is 112 feet above tide water; and the water at the cataract descends 82 feet. The rock is a hard mica slate, whose strike is N. a little W. by the needle, and whose dip is about 70° easterly. Consequently the water has acted upon the edges of the strata, and in circumstances poorly adapted to erosion. Yet as you stand upon the high bank near the falls, and look to the south, you see a gulf, from 60 to 65 feet high, with almost perpendicular walls of naked rock, extending nearly four miles. One cannot stand there and not be satisfied that the river must have worn out that gulf. Indeed, in going towards Georgetown, he will see that in many other places the work of erosion has been going on. And when we see the unfavorable position of the rock for being acted upon at this place, and the great amount of erosion, we can hardly avoid the conviction that a greater work has been done here than at Niagara; as indeed we might expect, when we remember that the rock over which the Potomac flows is probably much the oldest.[1]

14. *Passage of the Hudson through the Highlands.*—This celebrated gorge is nearly twenty miles long, and is remarkable for being worn out so that its bottom is below mean tide water. The hills on its sides rise in some instances as much as 2600 feet, and in many places the walls are very precipitous. The rock is gneiss, of a kind not easily disintegrated or eroded. Nor is there any evidence of any convulsive movement in the strata.

While, therefore, this is clearly a case of erosion, it seems almost equally obvious that the waters of the present river could not have done it: for they are too quiet, and have so little descent that tide water extends nearly 100 miles up the river beyond the Highlands: and, moreover, the low level of the bed of the gorge precludes the idea of a former cataract, whose recess might have accomplished the erosion. This, therefore, was probably a work mainly performed in some past period, when the continent was at a higher level. It was doubtless the joint result of oceanic and fluviatile action: for it is too crooked to allow us to impute it all to the ocean. Very probably the whole process was gone through at different periods, with long intervals, it may be, of rest. There is no evidence

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[1] I visited this spot in 1849, in company with Professors Henry and Guyot, Count Pourtales, and Mr. Saxton; and from these gentlemen I obtained several of the facts mentioned in the text. This same gorge is given as an example of the erosion of a river in Hutton's Theory of the Earth, by Playfair.

that much of it was effected since the drift period. Most likely it is a valley of very great antiquity.

15. *High Falls on the Hudson, in Luzerne, Warren county, New York.*—I depend entirely upon Professor Emmons' account of this gorge, in his Report on the Second Geological District, p. 188. It lies at the junction of gneiss and Potsdam sandstone. It is a mile long, and the wall of gneiss rises in some parts of this distance to the height of 100 feet. From Professor Emmons' description, I should judge this to be a genuine example of river erosion.

16. *Little Falls on the Mohawk, Oneida county, New York.*—The rock here is gneiss, through which the river has cut its way. Professor Vanuxem says that on its east side the walls of rock are 100 feet high, and that westward it gradually declines in height. The length of the gorge I am unable to state. It is an unequivocal example of river erosion: for pot-holes are found at various heights in its walls.—*Vanuxem's Report on the Geology of the Third District*, p. 208.

17. *Gorge on the Ottaqueechy river, at Hartford, in Vermont.*—The river here passes through a gulf a mile long, one side of which is 100 feet high and continuous: the opposite side being more irregular. Falls exist at Queechy village, 20 feet high, a mile above the gulf, with pot-holes on the sides and the bottom. Between these and the gulf are meadows, with seven terraces on one side of the river, and four on the other, as given in my paper on Terraces. Probably to determine the amount of erosion here, we must add the length of the gulf to its distance below the falls. But my examination of the spot was so hasty that I could not give a sketch of its features. The walls forming the gulf are mica slate, with trap, which Professor Hubbard supposes to have once occupied the gorge.—*American Journal of Science*, vol. IX., *New Series*, p. 160.

18. *Grandfather Bull's Falls, on Wisconsin river, in gneiss, mica slate, and trap.*—The cut is one and a half miles long, and 150 feet deep. Professor Owen describes another cataract a mile further up the stream, in trap; and the two may perhaps have formed parts of one continuous erosion, though more probably the work may have been going on contemporaneously at both places. *Owen's Report to the Government, in* 1848, p. 97.

19. *Gates of the Rocky Mountains.*—This remarkable chasm lies near the head waters of Missouri river, where it emerges from the Rocky Mountains. The average height of the walls is 1200 feet, and the chasm nearly six miles long. I am not sure that the rocks are crystalline, or hypozoic.—*Encyclopedia of Geography*, vol. III., p. 373.

20. *Sixty miles easterly from the Gates of the Rocky Mountains the Missouri forms a succession of cataracts, second only to Niagara.*—In the space of seventeen miles, the river falls 360 feet, beside the great fall of 90 feet. I refer to this place as probably affording, like the last, a striking example of river erosion.—*Encyc. Geog.*, vol. III., p. 373.

21. Robert Maclagan, Esq., of the Bengal Engineers, who has resided ten years near the Himalaya Mountains, informs me that on the Sutlej river, there is a gorge through gneiss, as much as 1500 feet deep and a mile long. Since his return to Europe he has sent me the following letter on this subject:—

EDINBURGH, 129 GEORGE STREET, *February* 10, 1854.

MY DEAR SIR: In course of conversation with you at Amherst, when I enjoyed the pleasure of a visit to your house, I communicated to you my impression of the height of certain precipitous cliffs on the banks of the Sutlej river, in the Himalaya, mentioning, that to the best of my recollection, I had estimated them at the time to reach the height of 1500 feet. I find on referring to my notes that I was correct in this recollection. I had set them down as of that height and possibly higher. The place is on the Sutlej, about seven miles above the confluence of the Buspa, in the district called Koonáwur, the great grape-growing country of the Himalaya. In addition to the note of the estimated height of the cliffs, I had observed in my note-book that they were very precipitous, almost and sometimes quite vertical. The path was all along the face of the cliff, now mounting high up to avoid some impracticable projection, and again similarly descending; the ascents managed by rude steps, at times very high and perpendicular. The path throughout a mere ledge, often extremely narrow, and occasionally supplemented by a trunk of a tree thrown across a chasm and in contact with the vertical face of rock, its ends resting on the projecting ledges forming the path.

The above is the description of the place as obtained from my note-book. At the base of this cliff flowed the Sutlej, here a very full and impetuous river. The rocks are gneiss and clay slate.

I am ashamed to have so long omitted to write to you and give the above information, which may be interesting, as confirming what I stated to you, with only half confidence, at Amherst.

22. The famous Cow's Mouth, in the Himalaya mountains, appears to be an enormous gorge cut by the Ganges, through a part of that chain. Some other similar cuts are described on that river; but I have not the authorities at hand for a minute description.

23. *Ravines on the west side of the Sierra Nevada Mountains, in California.*—The general character of the western slope of these mountains is thus stated by Philip T. Tyson, Esq., in his Report to the Government, on the Geology of California (p. 7): "The western flanks of the Sierra, as far as observed, consist of a vast mass of metamorphic and hypogene rocks, stretching from the Sacramento valley to the axis of the mountain. This mass of matter has an average slope from the valley upwards of 180 feet to the mile, thus giving a great rate of fall to the streams which rise in the vicinity of the snow peaks: these, aided by the decomposing energies of atmospheric agents, have excavated ravines of enormous depths, reaching along some branches of the American river at least 3500 feet. Into these, other ravines open with their innumerable tributaries, which, by intersecting the country in every direction, give it the appearance of a group of rounded and conical mountains." The following are examples of these ravines:—

1. South Fork of Yuba river: about 3000 feet deep.
2. North Fork of the American river: 3000 feet deep.
3. Middle Fork, not quite so deep.
4. South Fork, of a similar character.
5. Mokelumne river: 2000 feet.

The following extract from a private letter, from Mr. J. S. Daggett, principal of the Academy, in Americus, Georgia, gives so clear an idea of some of the features of the western slope of the Sierras of California, that I take the liberty, without consulting him, to insert it:—

"In the passage from San Francisco to the mining or mountainous region of the interior of the State of California, one cannot but be sensibly impressed with the geological features of the country, which give indication, amounting almost to positive proof, that the whole of that part of the State has

(recently) been submerged in the waters of the ocean. The very entrance to San Francisco bay, has evidently been made by the erosive power of the sea; it being not more than a quarter of a mile in width, with cliffs rising nearly perpendicularly several hundred feet on either side. And the mouth of the Sacramento river is still less in width, and having similar cliffs of solid stone, through which in time it has worn its way down to its present level. This is where it forms its passage through the coast range of the Sierra Nevada mountains, between which and the interior range lies the valley of the Sacramento. This valley is remarkable for its appearance of having once been the bed of an inland sea. You ascend the river some eighty miles from its entrance into the bay, by steamer, and after having passed the coast range, its banks stretch away into the vast level of the plain, with nothing to intercept the view but the tall waving grass and weeds. You then proceed about the same distance by stage to the mountains, and as you are whirled along over an almost level surface of sand, gravel, and marl, occasionally crossing the beds of rivers now dry, you are led to think that where you are now riding leisurely along, the mighty giants of ocean once sported and played. On leaving the valley to ascend the mountains, you see on either hand, stretching away to the north and south, perpendicular cliffs of basaltic rock, and vast columnar palisades, which present every appearance of having once withstood the action of the waves. On arriving among the mountains, the rocks indicate their volcanic origin, and present a varied and interesting aspect. I never witnessed scenery more grand and terrific than that on the rivers that flow down the western slope of these mountains. You are walking along over gentle eminences and little vales sprinkled with a thousand various flowers, and crowned with giant pines and cedars, when suddenly your ear catches the faint roar of distant waters, and immediately you are standing upon the brink of a precipice more than two thousand feet in perpendicular height, at the base of which you see the river foaming and dashing along, over rocks and cliffs, and madly seeking its way to the far off valley of the Sacramento, the opening to which you can just discern in the distance. Turning your eyes towards the source of the river, you behold the eternally snow-clad summits of the Sierras, peering high amid the clouds, and reflecting the beams of the sun. Opposite to you you see the various rock formations through which the river for numberless years has been cutting its way. Occasionally veins of quartz appear like banks of snow amid augitic and feldspathic granite, awakening interesting conjectures in the scientific mind. These manifestations of power have an effect of awe and sublimity upon the mind of the beholder, and lead him to wonder and adore the Omnipotent Creator."

24. *Passage of the river Zaire through the mountains, a distance of* 40 *miles, in Central Africa.*—The width of the stream is from 300 to 500 yards. The channel, everywhere "bristled with rocks" of mica slate, quartz rock, and syenite: in many places they were "stupendous overhanging rocks."—*Tuckey's Narrative,* pp. 176 and 349.

25. *Valley of erosion in the western part of New Fane, in Vermont.*—Upon a lofty hill in the west part of New Fane, is an extensive bed of serpentine, associated with soapstone, running nearly north and south. On the west side the hill slopes rapidly towards a small stream, which lies a little over 300 feet below the summit. A similar slope rises on the west side of the brook, extending into Dover. In the soapstone bed, near the top of the hill, are distinct pot-holes, which I regard as decisive evidence that a stream once ran there and formed a cataract. The conclusion is irresistible that the present stream, or its progenitor, once ran over this spot, and consequently that broad valley has been subsequently worn out. On Plate XII., Fig. 7, I have exhibited this valley with its sides having the slope which was determined by the clinometer.

This is an instructive case. For if this valley has been the result of river action, one could easily be made to believe that almost any other valley in the mountainous parts of our country had a similar origin.

2. *In Metamorphic and Silurian Rocks and newer Sandstones.*

1. *Gulf between Lake Ontario and Niagara Falls.*—These falls are at present six and a half miles from Lake Ontario, at Lewiston: and the whole distance the river runs in a gulf, which at the falls is 160 feet, and at Lewiston, 300 feet deep, and generally about twice as wide at the top as at the bottom. The rocks passed through by the receding falls are the Medina sandstone, the Clinton group of limestone and shale, and the Niagara limestone and shale. All these rocks, except the Niagara group, having a slight southerly dip, have disappeared beneath the bed of the river, and the falls are now in the Niagara group entirely, the shale lying beneath the limestone.

At the Whirlpool, a little more than three miles below the falls, on the west bank of the river, the continuity of the rock forming the bank is interrupted by a deep ravine filled with drift materials. This ravine may be traced two miles in a northwest direction, and from thence another depression can be followed to Ontario, at St. Davids, four miles west of Queenston.

It appears probable, as Professor James Hall has shown in his Report on the fourth District of New York, p. 389, that this ancient ravine may have been formed by oceanic rather than fluviatile action. For its opening on the lake at St. Davids is two miles wide: while that of Niagara river is about a third of one mile. And width of opening is one of the peculiarities of oceanic action, when it forms indentations along a coast, save in the case of purgatories, which are dependent upon a peculiar structure of the rocks. Although, therefore, it be not certain that Niagara river, or the river on a former continent that corresponded to the present Niagara, emptied into Ontario through this ancient ravine, yet since the ravine can be traced no further than the present river, this probably was the lowest part of the country between the falls and Ontario, and not improbably, therefore, the water of lake Erie would find this outlet into Ontario. It is clear, however, that the present channel of the river from Ontario to the falls, has been excavated since the drift period. For when the ravine to St. Davids was blocked up by drift materials, the stream would be forced to find its present rocky channel. Even though the drift rose only a foot higher than the rocks, it would as effectually force the waters over the rocks as if it formed a mountain. Could the river have once surmounted the drift, its work would have been comparatively easy in wearing out a bed through the old ravine. But till it was able to flow over the barrier, it would have no power over it, and must commence its slow work of wearing away the solid rock. The present gulf shows us what it has done since the drift period.

The above case, as well as the three following examples, are treated in much greater detail, and with much ability, by Professor James Hall, in his Report on the fourth District of New York.

2. *Gulf of Genesee River between Rochester and Lake Ontario.*—The Genesee river is remarkable for the striking examples of erosion which it exhibits. Beginning at its mouth, on the south shore of Ontario, we find three cataracts between that point and Rochester, which is about seven miles. Three distinct groups of

strata are crossed, viz: the Medina sandstone (lowest), the Clinton group next, and the Niagara group highest. It is evidently the different hardness of these groups, or varying facility of decomposition, that have produced these falls. In such a case we have indubitable proof that the river has done the work. These falls at first were but one, and at this time the lower ones are gaining probably upon the upper one, and the time may come when they will unite again.

A few miles east of the mouth of Genesee river, the Irondequoit creek empties into the lake, flowing in a deeper channel than the Genesee. But it passes through deposites of sand and gravel, and Professor Hall suggests, with much probability, that the Genesee once ran in the channel of the Irondequoit. But when that was filled with deposits of sand and gravel, and the region elevated, the Genesee was turned westward and compelled to cut out its present rocky bed, like the Niagara, of about seven miles in length. I am not able to state the amount of descent in the three falls: my aneroid gave 107 feet for the height of the largest at Rochester.

3. *Gulf of the Genesee River between Mount Morris and Portage.*—We have at this place a still more remarkable example of a postdiluvian cut in the rock in consequence of the filling up of the old channel. From Rochester to Mount Morris the Genesee river occupies for the most part a broad valley with no gorges of importance. But at Mount Morris it issues from high walls of Devonian rocks (the Portage and Chemung groups), and if we follow its course upwards to Portage, fourteen miles, we shall find its bed to be a deep cut in solid rock much of the way, with nearly perpendicular walls, but sometimes sloping so as to admit narrow meadows. It is not till you get considerably above St. Helena that you come to cataracts. In Portage, within a distance of less than two miles, are three falls, whose whole amount, with the intervening rapids, by my aneroid barometer, is 370 feet. The falls are said to be 60, 90, and 110 feet. *Am. Journ. Sci.*, vol. XVIII., p. 209. The depth of the gorge in some places is not less than 350 feet, and its width only about 600 feet, the banks being nearly perpendicular. Were the quantity of water in Genesee river as great as in Niagara river, the scenery on the former at Portage would be more imposing, on account of the greater depth of the gulf. As it is, it is well worth a visit, now easily made, as the railroad from Hornellsville to Attica crosses the river a little below the middle falls, if I rightly recollect.

In passing from Portage at the south end of this gorge, and near the upper falls, towards Nunda, we rise upon a deposit of sand and gravel of great depth, according to my measurements, 235 feet thick at the head of this upper fall. This deposit extends to Nunda, which place, by the aneroid barometer, lies 135 feet below the Genesee at Portage. From Portage a canal extends through Nunda to Mount Morris, following down from the former place a tributary of the Genesee. I fully agree with Professor Hall in his suggestion, that this was once the bed of the Genesee river: which being filled with drift and terrace materials, while the country was yet beneath the ocean, was compelled, upon the emergence of the land, to find a new tortuous channel more to the left. The result has been that it has cut out its present channel; that is, the deep gorge between Portage and

Mount Morris, since the drift period. I copy on Plate XII., Fig. 3, Mr. Hall's sketch illustrative of this view. On the right is shown the present bed of the river, and on the left, the ancient valley, now filled with sand, gravel, and clay.

4. *Bed of Oak Orchard Creek in Orleans county, New York.*—This is a small stream that empties into lake Ontario, passing across the same strata as the Genesee, viz: the Medina sandstone and the Clinton and Niagara groups. As we might expect, we find a similar series of cataracts and rapids: but I am unable to give any details as to their height, distance from one another, &c. The case is interesting, however, as lending additional confirmation to the views already presented, as to the fluviatile origin of the erosions in such streams as the Niagara and Genesee.

5. *Gorge on the Au Sable River in Essex county, New York.*—On the west side of lake Champlain, not far from Keesville, this river has cut a passage for a great distance through the Potsdam sandstone, which shows strikingly the excavating power of water. At Birmingham is a gorge two miles long and 100 feet deep. The best place for visiting it, is at a spot called High Bridge, where stairs have been cut in the walls to the bottom of the gulf, and as you stand there, the frowning and even overhanging walls almost shut out the light of day. No man at that spot could imagine any other agency but the stream itself to produce such a gulf. I mean no man accustomed to reason upon this class of geological phenomena. The average width of the gorge is only from 20 to 40 feet.

This spot may be reached by steamboat and two or three miles land travel, from Burlington, Vermont, and well repays the visitor.—*Emmons' Geological Report on the Second District*, p. 266.

6. *Water Gap on Delaware River, in New Jersey.*—Macculloch, in his Geographical Dictionary, states this gap to be 1200 feet deep and two miles long. I have not visited the spot, nor have I been able to ascertain whether the rocks be crystalline or Silurian.

In examining the valley in which Port Jervis and Delaware are situated, 40 miles above the gap, on Delaware river, I became satisfied that this river once ran northeasterly towards the Hudson river. And I am informed by H. N. Farnum, Esq., of Port Jervis, that the summit level of the Delaware and Hudson canal is only 115 feet above the Delaware opposite Port Jervis. If, therefore, the Water Gap were closed to the height of 115 feet, plus the descent of the river between the gap and Port Jervis, the Delaware would be turned into the Hudson. Such I can hardly doubt was the course of its predecessor on a former continent. But during the last submergence of that region, the old bed was filled with gravel and sand, so as to turn the Delaware towards the Water Gap, and probably some of the erosion there has been effected since the last emergence of our continent. The valley of the Delaware and Hudson canal, therefore, adds another example of an antediluvian river bed. I do not, however, feel so confident in this conclusion as I should if I had examined the whole ground.

7. *Gorge on Delaware River from Port Jervis to Narrowsburg.*—This is a deep and crooked gorge about 25 miles long, exhibiting some of the wildest scenery in our country, yet distinguished by two works of art of great magnitude and import-

ance: one is the canal leading from the coal mines of northern Pennsylvania; the other, the Erie railroad: both cut out of rock in many places, and overhung as it were by ragged precipices. It is impossible to ascertain the depth eroded by the river, because the banks are so irregular. Near the lower end, however, it is obvious that Mount Butler, on the New York side of the river, once constituted the barrier that has been cut through. It is 750 feet above the river at its base, and I thought I discovered traces of river action nearly all the way upwards on its steep face, and in some places on the top, although drift striæ are found in some prominent places. From Narrowsburg to Port Jervis the river descends, according to the aneroid barometer, 215 feet; so that if the barrier was once closed as high as Mount Butler, a narrow lake must have reached much further than Narrowsburg.

The course of the stream through this gorge is quite crooked. Of course it has been thrown with great power against particular spots and worn them away more rapidly, so as to form flats on the opposite side. In such cases these flats are almost invariably occupied by terraces of rather coarse gravel and considerable elevation. The serpentine course of the stream precludes the idea of the ocean's having worn out the gorge to any great extent.

8. *The Grand Cañon on Canadian River, in the country of the Camanche Indians.*—The southwestern portion of the United States, this side of the Rocky Mountains, is remarkable for the numerous deep gulfs through which the rivers run. These are called *Cañons.* Often they occur in a level region, where the strata, usually sandstone, lie nearly horizontal. In such a case the traveller, as he passes over the plain, sees no signs of a river till he finds himself suddenly stopped by a gulf, it may be several hundred feet deep, with walls nearly perpendicular, and sometimes for a day or two may he travel along the stream, unable to find a spot where he or his animals can get to the water. He meets with another difficulty, also, if he passes along the stream in the hope of finding a crossing place. When he comes to a tributary stream, he will find most likely a cañon, nearly as deep as on the main river, and he will be forced to diverge along the tributary, till he can find a passage over the gulf. Thus will he be compelled to deviate almost continually from his direct course, and moreover be tantalized by the sight of water in the inaccessible gulf below him, while his animals are nearly perishing with thirst.

I apprehend that travellers apply the term *cañon* to mountain gorges as well as the gulfs above described, and doubtless it would be proper to use the term in describing eroded gorges in the northern parts of our country; certainly to such as exist on the Niagara and Genesee rivers. But some of those described by officers connected with the United States army, are of a depth and extent much greater than any that have been mentioned. I shall give only a few examples, partly because out of the many that have been described by travellers, the facts respecting them are not given with sufficient definiteness to answer my purpose.

Some writers do, indeed, speak of convulsions as the cause of these cañons, just as they do concerning the gulfs at Niagara and Portage. But the fact that they exist along the tributaries, as well as the main stream, shows that they are the

work of erosion. For when have faults been known to take the ramified form of the tributaries to a river?

Lt. J. W. Abert, in his Report to the Government (p. 22), describes the Grand Cañon on the Canadian as an immense gulf, several hundred feet deep, with almost perpendicular walls. Mr. Stanley says, "we travelled fifty miles, the whole of which distance is bounded in by cliffs several hundred feet high, in many places perpendicular." Lt. Peck found the walls to be about 250 feet high, but he does not mention the length of the cut. The rock is described as shale.

9. *Cañons on the Pecos River, in New Mexico.*—These are thus described by Capt. S. G. French, in his Report to the Government, of a route over which he passed from San Antonio, in Texas, to El Paso del Norte, p. 45. "The Pecos is a remarkable stream, narrow and deep, extremely crooked in its course, and rapid in its current. Its banks are steep, and in a course of 240 miles, there are but few places where an animal can approach them for water in safety. Not a tree or bush marks its course; and one may stand on its banks and not know that the stream is near."

10. *Cañon of Chelly, in New Mexico.*—On the Map of Lt. James H. Simpson, in his Report to the Government, of an expedition among the Navajos Indians, west of the Rio Grande, we find no less than four Cañons laid down and noticed. But the most remarkable is that of Chelly, on the Rio de Chelly of Simpson, but the Red River of Monk's Map, in long. 109½° and N. lat. 36°. It is cut through red sandstone: its width at bottom varies from 150 to 300 or 400 feet: the height of its perpendicular wall is from 200 to 800 feet: and its whole length not less than 25 miles. This is certainly one of the most remarkable defiles that have ever been described. A view of this cañon, eight miles from its mouth, as given by Lt. Simpson, has been copied and accompanies this paper. See Plate XII. fig. 9.

11. A cañon still more remarkable, certainly for length, has been described by Capt. R. B. Marcy, of the United States Army, in a lecture before the American Geographical and Statistical Society, in New York, March 22, 1853, giving an account of his exploration of the head branches of Red river, in Texas. This river takes its rise in the desert table land, called Llano Estacado, which is elevated above the sea 3650 feet, and which extends from the Canadian river southerly for 400 miles, between 101° and 104° W. long., and 32° 30′ N. lat. to 36° 20′. The gorge on Red river, as it comes out from the sandstone of this *mesa*, says Capt. Marcy, "is 70 miles long, and the escarpments from 500 to 800 feet high on each side, and in many places they approach so near the water's edge, that there is not room for a man to pass; and occasionally it is necessary to travel for miles in the bed of the river, before a spot is found where a horse can clamber up the precipitous sides of the chasm." Near the upper part of the chasm, he says, "the gigantic walls of sandstone, rising to the enormous height of 800 feet on each side, gradually closed in, until they were only a few yards apart, and at last united above us, leaving a long narrow corridor beneath, at the base of which the head spring of the principal branch of Red river takes its rise." "The magnificence of the views that presented themselves, as we approached the head of the river, exceeded anything I had ever beheld. It is impossible for me to describe

the sensations of intense pleasure I experienced, as I gazed on these grand and novel displays of nature."—*See also Capt. Marcy's Report*, p. 55, *et seq.*

12. *Hot Spring Gate, on the River Platte, in about* 107° *W. longitude.*—The river here passes through a hill of white calcareous sandstone, a distance of about 1200 feet, with a depth of about 360 feet. At both extremities is a smooth green prairie. Col. J. C. Fremont has named, described, and given a sketch of this gorge in his first Report, p. 55.

13. *Rapids in St. Louis River, west of Lake Superior, towards the Portage aux Coteaux.*—The gorge is 36 miles long at least, and the walls from 30 to 40 feet high, in argillaceous slate. In that distance are four distinct falls, each made up of several distinct cascades. Here doubtless the work of erosion and retrocession is going on at every cascade.—*Owen's Report on Wisconsin and Iowa, in* 1848, p. 79.

14. *Cañon in the Rocky Mountains, on one of the branches of Snake or Lewis River.*—The distance through it occupied a half day's travel, the walls are very precipitous and high, and the rocks are sandstone, limestone, and gypsum.—*Parker's Exploration*, 3d edition, p. 87.

15. *Gulfs of Loraine and Redmond, in Jefferson county, New York.*—These appear to be genuine cañons upon the small streams flowing through the Trenton limestone, Utica slate, and Loraine shales of those towns. Those are the most striking upon South Sandy creek. The walls are perpendicular, and vary in height from 100 to 300 feet. The width of the gulf varies of course, and is sometimes as much as sixteen rods. The length of some of them is over twelve miles, reaching to the very starting-point of the streams.—*Emmons' Report on the Second Geological District of New York*, p. 408.

16. *Gorge on Cox River, in New South Wales, in Australia.*—This is 2200 yards wide and 800 feet deep, cut in horizontally stratified sandstone. From this valley Major Mitchell estimates that 134 cubic miles of stone have been removed.—*Am. Journal Science*, vol. IX., New Series, p. 290.

17. *Kangaroo Valley* is another example of erosion in the same country. It is two or three miles wide, and from 1000 to 1800 feet deep, opening outward through a comparatively narrow gorge. Professor Dana estimates the amount of rock necessary to fill the valley, and which has been removed, to be equal to "a rectangular ridge 12 miles long, two miles wide, and 2000 feet high."

The above are only two out of a multitude of valleys in New South Wales, which have been excavated in horizontal strata of sandstone. They are usually narrowest and deepest towards the sea, resembling a harbor with a narrow entrance. Professor Dana has shown in a conclusive manner, that these valleys are the work of running water, and not of convulsions or of original creation.—*Am. Journal of Science*, vol. IX., New Series, p. 289.

18. *Gorge of the Rhine, between Coblentz and Bingen.*—All that distance, nearly 50 miles, the river has cut across ranges of mountains of the older fossiliferous rocks, to a depth sometimes as great as 1000 feet. The gulf is a true mountain gorge, and the banks are so precipitous as scarcely to afford room for a narrow terrace. The idea that the waves of the ocean, or a rent by internal forces, pro-

duced this gulf, is made exceedingly improbable by the tortuousness of its course, which would prevent the action of waves, and would be followed by no volcanic rent. It corresponds, however, to the known effects of currents of water, when a country is undergoing drainage.

I might perhaps consider the gorge of the Rhine as commencing as far down as the Drachenfels, and extending even to Mayence. But the valley is a good deal wider at these extremities, and I prefer to confine this example to that portion of it which seems unequivocally the work of river action.

The strata cross the Rhine nearly at right angles, and appeared to me, from the steamboat, to dip 60° to 70° S. easterly.

19. *Valley of erosion in Dorset, Vermont.*—Those who have passed from Manchester to Rutland, in Vermont, on the Western Vermont railroad, will not forget how narrow the valley is, especially in Dorset and Danby. Its east side is formed by the Green Mountains, and its west side by a ridge not so high, which at its southern extremity has received the name of Dorset Mountain. Near the base of Dorset mountain the Otter creek takes its rise, and runs northerly into Lake Champlain, at Vergennes. Near the same spot rises the Battenkill, which runs southwesterly and empties into the Hudson at Greenwich. Both these streams are mere brooks at the base of Dorset mountain, and the idea that they ever wore out the valley in which they run, is quite absurd, especially as they flow in opposite directions. Dorset mountain, according to the careful measurements of Mr. W. A. Burnham, teacher in Burr Seminary, in Manchester, is 1627 feet above the valley, whose summit-level must be near the base of the mountain. This is, however, a valley of erosion; for near the top of Dorset mountain is a thick bed of white limestone, which is interstratified with a metamorphic talcose slate, sometimes called the Taconic slate. The mountain rises very precipitously from the valley, being almost perpendicular on its east side, and in the limestone, not far from 1600 feet above the valley, is a cavern opening towards the valley, and sloping towards the west, as represented in Plate XII. fig. 5. On exploring this cavern for several rods, I met with unequivocal evidence that it had been formed by running water. I traced it several rods into the mountain, and think it may be followed much further.

Now the conclusion is a legitimate one that a stream of water of considerable size once, and for a long time, ran through this opening. Consequently the valley east of it must have been filled to the height of the stream, in order to form a surface for a river bed. Consequently the valley, 1600 feet deep, and many miles long, must have been excavated since that period; for I saw no evidence of any upheaval of this mountain at a subsequent date.

What agencies were concerned in this work, it may be difficult fully to understand. It is certain that existing streams have not produced it. Drift agency, while the continent was beneath the ocean, may have had some effect; as, also, the slow action of the waves during the vertical movements of the land. But the length, narrowness, and depth of the valley, and the steepness of its sides, agree better with river action, and I cannot doubt that the work was mainly accomplished by that agency on some continent long, long anterior to the present.

Further north, on the same continuous ridge, is at least one other cavern in limestone, which is said to have been penetrated 150 feet in depth, without reaching its bottom. But I have not visited it, and know neither its height above the valley, nor whether it was an ancient river bed: though every such cavern, which I have visited in the limestone of New England, has seemed to have been thus produced.

If this valley in Dorset was formed by aqueous erosion, it is highly probable that the many other deep and narrow valleys in the same metamorphic rocks in Vermont and Massachusetts, especially in Berkshire county, were formed in a similar manner. On no other theory could I explain their existence, even had we not this striking fact of the eroded cavern on the top of Dorset mountain.

I might extend this inference to a large part of the deep valleys of our country. At least, such facts afford a presumption that many of them were probably the beds of rivers on former continents. Here, then, it appears to me, is an interesting field of geological inquiry, rarely entered, yet capable of exploration. I mean the determination of the period and manner in which our ancient valleys have been formed.

20. *Gorge on New River, a tributary of the Kenawha, in western Virginia.*—Dr. Hildreth describes this gorge as having nearly perpendicular walls of 800 feet in height, and its whole length is 50 or 60 miles. Indeed the entire valley of the Kenawha river, so far as I have ascended it, appears manifestly to have been worn out in the nearly horizontal sandstone, shale, and fire-clay, of the coal formation. The hills along its lower part, however, rarely rise higher than 400 or 500 feet.—*American Journal of Science*, vol. XXIX. p. 91.

21. *The Valley of the Mississippi, for two hundred miles above the mouth of the Missouri.*—I select this part of this valley, because the proof of its erosion seems quite obvious, by looking at Professor Owen's geological map, appended to his Report upon Wisconsin, Iowa, and Minnesota; or upon a similar map in Taylor's Statistics of Coal. On the east side of the river and at some distance, is exhibited the Illinois coal field; and on the west side, that of Missouri and Iowa. Approaching the river from either side, we find the coal measures swept away, and the carboniferous limestone, the next rock beneath, brought to light. Still nearer the river, we find rocks of a still older date, because the valley is deeper. How obvious that these coal fields were once united, and that the coal measures have been swept away by the action of water! What portion is gone I am unable to state: but the fact that powerful erosion has taken place seems too evident to be doubted. Most other river beds present similar facts: but they do not usually stand out so distinctly.

22. *Big Cañon on the Rio Colorado of the West.*—This occurs in W. long. 115° and N. lat. 36°; but I have not been able to find any detailed account of its extent. Where Capt. Sitgreaves struck a cañon on the Zuñi, or Little Colorado, which he was assured extended to the Rio Colorado, its depth was 120 feet, less probably than that of the Big cañon.—*Sitgreaves' Report to Government*, p. 8.

23. *Dalles of the Wisconsin River, in Wisconsin.*—The length of this gorge in sandstone, is five or six miles, and the height of the wall from 40 to 120 feet.—*Owen's Report on a Survey of Wisconsin, &c.*, p. 517.

3. *In Limestone chiefly.*

Some of the cases already described are partly in limestone and some of those now to be presented are partly in other rock; but I shall bring those only under the present division that are chiefly in limestone.

1. *Gulf at the Natural Bridge, in Rockbridge county, Virginia.*—The width of this gorge is 50 feet at bottom, and 90 feet at top; and the height of the bridge is 215 feet above the stream; its length I have not been able to ascertain.

2. *Gulf at the Natural Bridge, in Lee county, Virginia.*—The walls here are 339 feet high, and the width of the stream from 35 to 55 feet. The length of the gulf is not given, but the stream itself (Stock creek) is only a few miles long.

3. *Glenn's Falls, on Hudson River, Warren county, New York.*—These are in black limestone, and the gorge is of considerable depth and length, but though I have visited the spot I have made no measurements. The height of the falls is about 50 feet.

4. *Trenton Falls, on West Canada Creek, in Oneida county, New York.*—These are also in the black Trenton limestone. The gorge is very deep and extends for at least two miles; in which space are six cataracts. In passing through this gorge I was much impressed with the power of water to wear away unyielding rock.

5. *St. Anthony's Falls, on the Mississippi.*—The surface rock, over which this large river, 1800 feet wide, is precipitated, is limestone, underlaid by friable sandstone. The latter easily disintegrates and undermines the limestone, which falls at length by the force of gravity, piece after piece. In this manner have these falls receded seven miles from the mouth of St. Peter's river. The fall of water at present is only about 17 feet. From these falls to the mouth of the Wisconsin, some 130 miles, the river passes through limestone, and has walls of rock, but I have not met with any description definite enough to decide whether its bed has been eroded all the way.

6. *Cañada (little Cañon), of Santa Domingo, in Oaxaca, a province of Mexico.*—This gorge is from 10 to 30 feet wide, 25 miles long, and the immediate walls 300 feet high. Back from the river a mile, the mountains rise to the height of 2000 feet. This case was described to me by the late Mr. George R. Ferguson, who was employed as an engineer upon the Tehuantepec railroad. The rock is limestone.

7. The same gentleman mentioned another gorge on the river Tobasco, in the province of Chiapas, in Mexico. It is 300 feet deep, but its length he could not give. This also is in limestone.

8. *Defile of Karzan, on the Danube, on the borders of Hungary and Turkey, a little above Orsova.*—The river here is only about 600 feet wide, and the perpendicular walls of limestone and slate, are 2000 feet high; and the water is 170 feet deep. For many miles above this, a similar defile exists, and it is one of the most remarkable gorges, or rather succession of gorges, between successive basins, on the globe.—*Murray's Handbook for Southern Germany*, 5th edition, p. 511.

9. *The Via Mala, on the Rhine, near Thusis, in Switzerland.*—The rocks are slate and limestone, and the river is here compressed for the distance of four miles, into

a gorge often not more than 30 feet wide, but 1600 feet deep; said to be the most remarkable defile in Switzerland. A road has been blasted through the overhanging rocks, high above the river, the Middle Bridge being not less than 400 feet high. Yet, in 1834, the river rose nearly to this bridge.—*Handbook for Switzerland.* Paris, 1849, p. 222.

10. *Wady Barida, in Anti-Lebanon, in Syria.*—This is a long gorge (length not given), in limestone, with walls from 600 to 800 feet high.—*Described by Rev. Mr. Thompson, American Missionary, in the Bibliotheca Sacra,* vol. V. p. 762.

11. *Gorge and Natural Bridge on Dog River, the Lycus of the Ancients, in Mount Lebanon.*—The width of this gorge is from 120 to 160 feet; its length six miles, and the height of the bridge, 70 to 80 feet. Span of the arch, 163 feet.—*Described by Mr. Thompson, in the Bibliotheca,* vol. V. p. 2.

12. *Gorge in limestone and a Natural Bridge, on the River Litany, in Mount Lebanon.*—This stupendous gorge is many miles long: and so narrow in many places that persons standing on the opposite sides can converse. The walls are in the deepest part a thousand feet high. The bridge is formed by large rocks falling from the cliffs. This spot deserves more minuteness of detail. It is described by Rev. Eli Smith, of Beirut.—*Bibliotheca Sacra,* vol. VI. p. 373.

13. *On the Euphrates, near Diadeen, in Armenia.*—A natural bridge occurs here, 100 feet wide, 150 feet high, and more than 100 feet long. Another bridge occurs 50 rods lower down the stream, 40 feet high, and 100 feet wide. The banks of the river, for miles above and below these bridges, are 100 feet high. No less than eight hot sulphur springs occur on the banks of the river at the bridges, which reach down even to high water.—*Letter from Rev. Justin Perkins, D. D., American Missionary, dated at Ooroomiah, July* 20, 1848.

14. *On the River Raveondooz, near a town of that name in the Koordish Mountains.*—This river, says Dr. Perkins, is "about as large as Chicopee river (in Massachusetts), and is engulfed between perpendicular limestone banks, that rival in awful grandeur those of the Euphrates, above Diadeen, and are indeed quite unparalleled by anything of the kind I have ever seen, even the banks of the Niagara below the falls; except that the river itself is small. These perpendicular rocky banks are in some places nearly a thousand feet high."—*Letter from Dr. Perkins, dated July* 9, 1849.

15. "There is a similar gorge, on our return route (from Mosul to Ooroomiah), on the river Sheen, in Jeloo."—*Same letter.*

16. *Wady el Jeib, at the south end of the Dead Sea, in Palestine.*—This is a gorge lying at the bottom of Wady Arabah, a wady within a wady, and has been apparently excavated by the winter streams that flow northward into the Dead Sea. It commences 40 miles south of that sea, and terminates a few miles south of it, where a limestone terrace stretches across the wady Arabah. The width of the defile, at its lower part, is half a mile, and the height of its walls 150 feet. It is in soft limestone, belonging probably to the cretaceous formation.—*See Robinson and Smith's Bib. Researches in Palestine, &c.*

4. *In Unstratified Rocks chiefly.*

1. *Devil's Gate.*—Near the rock Independence, on the Sweet Water, in the Rocky Mountains. Length of the gorge, 900 feet. Height of the walls, 400 feet. Width of the gorge, 105 feet. In granite.—*Fremont's First Tour*, p. 67, with a drawing; also *Fremont's Second Tour*, p. 164, with a plate.

2. *The American Falls, on Lewis' Fork of Columbia River.*—Width of the river, which is contracted at the falls, 870 feet. From these falls the river runs between walls of trap, with occasional interruptions, to the Dalles, or "trough," of the lower Columbia, 800 miles.

3. *The Dalles, or "trough," and rapids, near the mouth of Columbia River.*—The basaltic walls here, although not of great height, are continuous for six miles. Perhaps I ought to consider this example as embraced in the last.—*Parker's Exploring Tour*, pp. 142 and 318.

4. *The Cascades on the Columbia*, 50 *miles below the Dalles, or falls.*—The walls are trap, from 100 to 400 feet high, and five miles long.—*Parker's Ex. Tour*, p. 142 and 318.

5. *Gorge on Columbia River, a little below Fort Wallah Wallah.*—This gorge in trap, is from two to three miles long, and 300 feet deep.—*Parker's Ex. Tour*, p. 132.

6. *Pavilion River*, which empties into the Columbia a little above Wallah Wallah, is walled up with trap some 15 or 20 miles.—*Same work*, p. 289.

It seems that the Columbia river and many of its tributaries pass through deep and almost continuous cuts in the hard trap for several hundred miles. The above cases are merely some of the most striking spots.

7. *The Dalles of St. Croix River, in Wisconsin*, 30 *miles above its mouth.*—This gorge in trap, is at least half a mile long, and from 100 to 170 feet deep.—*Owen's Report on a Survey of Wisconsin, &c.*, p. 164, *and a beautiful sketch on* p. 142.

8. *Gorge and Falls, on Pigeon river, in Wisconsin.*—This is near the mouth of the stream, which is 75 feet wide, falls 60 feet, and then pursues its way for 600 feet, in a deep trough in trap.—*Owen's Rep.*, p. 405, *with a sketch.*

9. *Adirondac Pass, in the Mountains of Essex county, New York.*—This, as described by Professor Emmons, appears to be an immense gulf in the peculiar granite, or hypersthene rock of that region, whose bottom is filled to a great depth with fragments of rock broken from the walls. Those walls on one side present a perpendicular front 1000 feet high, and three-quarters of a mile long. Professor Emmons thinks that the detritus is 500 feet deep, making the original gulf 1500 feet. Whether it was excavated by a river, or by the ocean, producing a purgatory, his description does not enable us to determine.—*Emmons' Report on the Geology of New York*, p. 216.

10. *Erosions in trap, in the Ghaut mountains of southern India.*—Probably the largest outburst or overflow of trap in the world exists in southern India, extending from latitude 16° to 25°, at least, or nearly 600 miles, and some hundreds of

miles east and west. The Ghaut mountains lie near the western coast, rising from 2000 to 7000 feet, with high table lands stretching away from their east side. This region is penetrated by numerous valleys, sometimes 600, 800, or even 1000 feet deep, whose precipitous sides exhibit numerous alternations of compact, amygdaloidal, and tufaceous trap, capped by laterite and red clay, in layers apparently horizontal. The same layers appear on both sides of the valleys undisturbed; showing, beyond question, that the depressions have been the work of erosion rather than of internal upheaving forces. These valleys are numerous, especially along the western face of the Ghauts, and the eye can often take in a distance of 10 to 15 miles; the layers of trap showing continuous stripes all the way; nay, much further, if the observer travels along the valley.

These are certainly striking examples of erosion by streams, in a country where we cannot suppose ice to have aided the work. But tropical rains are very powerful. I am indebted for these facts to Rev. Ebenezer Burgess, missionary at Satara, in southern India, and who was formerly a resident for years at Ahmednugger, which lies in the same great trap region. To him, also, I am indebted for the facts stated in the next example. He visited Table Mountain, on his return recently, and obtained specimens of the different rocks composing it.

11. *Table Mountain, at the Cape of Good Hope, in Southern Africa.*—This is a vast mass of horizontal strata of sandstone, some 600 or 800 feet thick, superimposed upon granite and older inclined sandstone and metamorphic slate. The height of the mountain is stated at 3800 feet; which makes it visible 30 to 40 miles at sea. That this outlier of sandstone, capping Table mountain, must once have had a wide extent, no geologist will doubt, nor can it be reasonably questioned that it has been brought into its present shape by the action of the ocean, when this was at a higher level, or the mountain at a lower level. The slate and lower sandstone, that are inclined at a large angle, must have been tilted up by a force beneath, or acting laterally. But if the mountain has been raised since the deposition of the horizontal sandstone, it must have been a secular elevation, bringing up the continent bodily and equably.

12. *Table lands and intervening Valleys in the vicinity of Natal, in South Africa.*—Accident has put into my hands two sketches of the scenery in that region, with a description, from the pencil and pen of Mrs. Lydia B. Grout, wife of Rev. Mr. Grout, American missionary among the Zulus; and these are too appropriate to the object of this paper, and too well executed to be lost. I therefore have taken the liberty to append these drawings (Plate XI. figs. 1 and 2), and copy the accompanying descriptions, from a letter written by Mrs. Grout.

A glance at these drawings will satisfy the geologist that they represent a region analogous to Cape Town, and this makes it probable that these table lands are very extensive in Southern Africa, since Natal is some 800 miles north of the Cape. And we see enough in the drawing and description to satisfy any one that the erosions in Southern Africa have been on the same great scale as on other continents.

"The scene," says Mrs. Grout, "which it (Plate XI. fig. 2) portrays, is about three

miles from our station. In going to it (the station), or rather to the brow of the hill or precipice on this side of it, we cross a table land like the one shown in the drawing. These table lands, with ten thousand little hills, are distinguishing natural features extending the whole length of the colony. Table lands are on each side of the valley of little hills. They are, however, broken at intervals, of perhaps about six miles; thus affording a passage to the large rivers that flow into the Indian ocean. Their terminations towards the valley are sometimes perpendicular precipices, several hundred feet in height, covered with bushes near the top, and breaking into numerous hills below. There is seldom a descent to the valley sufficiently gradual to allow a wagon to be driven down. I think there is not more than one such declivity from each table land."

"In some places these platforms are perpendicular for 20 feet or more at the top, and expose a face of sandstone, broken into a thousand fragments, which to a great extent retain their places. Sometimes, however, these fragments are strewn over the whole of the slopes of which I have spoken. There is an example in the foreground of the drawing (Plate XI. Fig. 2) on the right side. Some of the fragments, as exhibited, are very irregular, while others are rectangular. The width of the scene presented is perhaps four miles; but in most places the great valley is more extended. The widest part we have travelled over is about ten miles."

"Sometimes in the midst of these little hills single mountains rise, which seem to correspond in height with the table lands, and their sides present the same variety in appearance as do the latter. Examples of these mountains are given in the outline (Plate XI. Fig. 1). The tops are not more than 5 or 6 feet wide, and with the sides are covered with grass."

"It seems to an observer of this scenery, that the whole region, including table lands, mountains, peaks, and small hills, was once an immense plain, and that some mighty convulsion of nature brought them into their present state. Whether this great change was produced by fire or water, we are not geologists enough to decide."

These views of Mrs. Grout are doubtless correct, except "the mighty convulsions of nature," which were probably little more than the quiet and slow action of the present rivers, aided, perhaps, by the waves of a former ocean. But that no violent convulsion of nature has been concerned, is obvious from the horizontal position of the sandstone, forming the upper part of the table lands and the caps of the mountains. The case seems analogous to the *cañons* of our southwestern states.

This case might perhaps have been more properly introduced under the examples in sandstone. But I place it here in connection with the example from Cape Town, as it seems to belong to the same class of phenomena.

13. *Pass of Dariel Caucasus, on the River Terek, in Asia.*—Maculloch's Geographical Dictionary represents this pass as occurring in porphyry and schist, as being 120 miles long, and having walls 3000 feet high. Sir R. Ker Porter speaks of the walls as only 1000 feet high.—*Travels,* vol. I. p. 75.

14. *Source of the River Jordan, above Lake Huleh, in the mountains of Lebanon.*—Mr. Thompson, American missionary, describes it as a constantly deepening gorge, in basalt, six miles long.—*Bibliotheca Sacra*, vol. III. p. 135.

15. *Valleys in the volcanic islands of the Pacific Ocean.*—These valleys have been described, and their origin discussed with great ability, by Professor J. D. Dana, in his Geological Report of the United States Exploring Expedition. He divides them into three kinds: 1. "A narrow gorge with barely a pathway for a streamlet at bottom, the enclosing sides diverging upwards at an angle of 30° to 60°." 2. "A narrow gorge, having the walls vertical, or nearly so, and a flat strip of land at bottom, more or less uneven, with a streamlet." 3. "Valleys of the third kind have an extensive plain at bottom, quite unlike the strip of land just described." The valleys are one, two, or even three thousand feet deep, and the dividing ridges often so narrow as to be knife-like and tortuous. Professor Dana imputes their origin mainly to two causes: first, volcanic agency, which lifted up the mountains and produced inequalities and gulfs. Secondly, the action of rains producing brooks and rivers. The latter cause he thinks the chief one, though the ocean, especially when the islands were nearly submerged, must have produced some effect.

The phenomena of valleys in some parts of the great Appalachian coal field, as along the Ohio and Great Kenawha rivers, appear to me to sustain the view taken by Professor Dana, that streams of water chiefly have eroded the valleys of the Pacific islands. For along those rivers the coal measures lie nearly horizontal, and the rivers have evidently worn out their beds to the depth of some hundred feet, leaving bluffs of sandstone along their margin. And wherever brooks and streamlets have found their way to the main river we observe that they have worn out channels having the same steep sides as those of the Pacific islands. The ridges too, intervening between the brooks, are sharp, narrow, and tortuous, though not extremely so, like those of the Pacific islands. Now, in the horizontal coal strata, which have never been disturbed, we can impute the valleys and ridges to nothing but running water, and it is reasonable to refer the analogous phenomena of the Pacific islands to the same cause.

Conclusions.

From the facts that have been detailed, we may derive several inferences of considerable geological importance. With these I shall conclude this paper.

1. Some of the erosions that have been described, must have been commenced as early as the oldest rocks were consolidated.

They occur in the oldest hypozoic rocks, and were begun probably by the drainage of land at its first emergence from the waters. The hypozoic rocks are not indeed necessarily older than the fossiliferous. But sometimes they lie below the fossiliferous, and are too thick to be regarded as their lower metamorphic beds. I should place the following cases as among the earliest described in this paper:—

1. Valley of Connecticut river, which is for the most part formed in hypozoic rocks.

2. The Ghor, on Deerfield river, a tributary of the Connecticut: or rather the whole valley of Deerfield river west of Deerfield.

3. The valley of Hudson river, for the most part in hypozoic and the oldest Silurian rocks.

4. The valley of Agawam river, from Mount Tekoa, in Westfield, to the summit level of the Western railroad.

5. The cut at the summit level of the Northern railroad, in New Hampshire.

6. Dorset valley, on the west side of the Green Mountains, through which the small streams called Otter creek and the Batten kill now run. The rocks are hypozoic, or very old metamorphic.

7. Gorge on Little river, in Russell and Blandford, No. 13, in hypozoic rocks.

8. Gorge on the Potomac, below Great Falls, in Virginia, No. 15, in hypozoic rocks.

To these cases I might add probably nearly every valley through which rivers of considerable size run in the hypozoic regions of our country, especially of New England. But my object in this paper is not to describe all cases of erosions, but only to give some good examples, in order to call the attention of geologists to the subject.

As, however, it does not follow because a gorge is found in hypozoic rocks, that it is very ancient, I have thought that the following principles may enable us to decide with much probability whether a valley is of the most ancient class.

1. Such a valley must occur in the oldest rocks, viz: the hypozoic, early metamorphic, or Silurian.

2. It will have great width in its upper parts, its slopes will be gentle, its sides rounded, and with few precipitous gorges. Such effects could be produced only by oceanic agency, as the continent was repeatedly submerged and raised from the deep. The waves and currents, rushing back and forth through the gorges produced by streams, would give this breadth and rounded outline of the sides, and I know of no other cause that could have produced the effect.

3. The rivers in the oldest valleys have nearly ceased to deepen their beds, except perhaps where cataracts occur, and these are not usually of the most striking character.

4. The drift agency in such valleys has smoothed and striated the rocks nearly to the present level of the streams, and thus afforded proof that the beds have not been much deepened since the drift period.

2. The work of erosion in these oldest valleys must have been repeatedly interrupted, varied, and renewed, by vertical movements. Some of the continents, perhaps all of them, have been subject to such movements, as is obvious from the character of the strata and their embedded organic remains. At one period, for instance, dry land must have existed over wide areas, and then these must have been submerged to receive a marine deposit now covering them.

3. Some of the erosions that have been described in this paper are clearly the beds of antediluvial rivers: that is, of rivers existing upon this continent before its last submergence beneath the ocean; which beds were deserted when the sur-

face emerged from the waters: although essentially the same rivers as existed previously, must have been the result of drainage.

The grounds on which I refer the cases mentioned below and described in detail in this paper to the latest of former continents are the following:—

1. The occurrence of pot-holes in the walls of gorges, which are either dry, or the bed of a brook too small to have produced them.

2. The outlet of such gorges in one direction into valleys now containing streams large enough to have formed the gorges, and in the other direction, into valleys leading at a gentle descent to some rivers.

These two facts make it certain that the gorges were once the beds of rivers.

3. An accumulation of water-worn and, perhaps sorted materials, viz: gravel and sand, to a considerable depth. This accumulation appears to me to have been made during the last submergence of the land, and to be the cause that prevented the ancient rivers from occupying their old channels upon the drainage of the country, and compelled them, at least for a considerable distance, to find a new channel. I consider the following as examples of this phenomenon, most of them very decided; that is, of these antediluvial river beds.

1. An old bed of Niagara river, commencing on the Canada shore, near the Whirlpool, and passing circuitously to St. Davids, four miles west of Queenstown.

2. An old bed of Genesee river, extending from the mouth of Irondequoit creek, nearly to Rochester.

3. An old bed of the same river, extending from Portage to Mount Morris, some twelve or fourteen miles, now filled with sand and gravel.

4. Proctorsville Gulf, an ancient bed of Black river, in Cavendish, Vermont.

5. A former bed of Connecticut river, in Portland, Connecticut. Indeed there are two such beds: but I have examined the most easterly one with most attention. It is near the junction of the sandstone and hypozoic rocks, and is filled with gravel to the height of about 200 feet above the river at present. My impression is that the Connecticut ran in this channel on the last continent before the present, and that the detritus which was thrown into it during the last subaqueous sojourn of the continent, turned the river into its present channel upon the emergence of the land. But I am not sure that this old channel was occupied by the river at so recent a date. It might have been at a still earlier date. My doubts spring from the great height of the old bed above the present river.

6. Former bed of Delaware river, along the valley now occupied by the Delaware and Hudson canal, from Port Jervis, or Delaware, to Hudson river.

7. Bed of an ancient river in Antwerp, Jefferson county, New York. I venture to place this example among the river beds of the last continent, although I have never examined it. But taking Professor Emmons' description of the deserted river bed in that place, and looking at a map of the region, I venture to predict that it will be found that the Oswegatchie river once ran into what is now the Indian river, and was forced by the filling up of its channel when beneath the ocean, to take another very circuitous route to Ogdensburg.

8. An ancient bed of Agawam river, in Russell. See No. 10 of erosions in hypozoic rocks.

9. A similar bed on the same river, at Chester village (now called Huntington). See No. 11 of this paper, in hypozoic rocks.

10. A similar bed on the east branch of this same river, four miles above Chester village. See No. 12, in hypozoic rocks, of this paper.

4. Some cases of erosion described in this paper appear to have been mainly intermediate, as to the time of their formation, between the antediluvial river beds just enumerated, and the earliest formed in the hypozoic rocks.

I would not undertake to decide positively how many times this continent, or large portions of it, may have been beneath and above the ocean. But I do not see how we can escape the conclusion that it must have been submerged at least three times. During the Silurian period we must admit its submergence; and during the carboniferous period, certainly large portions of the surface must have been above the waters to allow a gigantic growth of plants. The triasic, oolitic, and cretaceous deposits, must have been made on surfaces beneath the ocean. The tertiary strata seem to have been formed chiefly in estuaries, and with dry land in the vicinity, which indicates a second emergence. The evidence that the same surface was beneath the waves during the deposition of drift, has been presented in the paper on Surface Geology: and we have the proof beneath our feet of the third emergence of our country during the alluvial period.

During all these vertical movements, erosions of the surface must have been going on. I have referred to some examples of this work, commencing at the earliest period, or during the first emergence and drainage of land: and also some cases referrible to the last upward movement. The following cases seem most probably to have been produced at an intermediate period, but precisely when (as to geological sequence rather than chronological dates), I am unable to determine.

1. The Proctorsville gulf, in Cavendish, Vermont. See the description in this paper, No. 14, in hypozoic rocks.

2. Gorge on Delaware river, from Port Jervis to Narrowsburg, in Pennsylvania. A very old erosion, perhaps among the oldest.

3. The cañons of the southwest, described in this paper. Very old.

4. Gorge on New river and the Kenawha, in western Virginia, in coal sandstone. No. 20, in fossiliferous rocks, of this paper.

5. Gorges in New South Wales, Australia, in sandstone. Nos. 16 and 17, in fossiliferous rocks.

6. Natural bridges in Virginia.

7. Do. on the Euphrates, near Diadeen, in Armenia.

8. Do. on Dog river, in Mount Lebanon.

9. Gorge on the river Ravendooz, in Kurdistan.

10. Wady el Jeib, in Palestine.

11. Via Mala, in Switzerland.

12. Defile of Karzan, on the Danube.

13. Old river bed, east side of Mettawampe, in Massachusetts.

14. Gorges through trap, on the Columbia river and its tributaries.

The grounds on which I refer these cases to a period intermediate between the

11. It is mainly at rapids and cataracts that rivers are now deepening their beds.

12. The details that have been given enable us to form some idea of the length of time that has elapsed since the close of the drift period.

The evidence on this point, rests on the assumption I have made in the preceding details, that certain old river beds that existed on the last continent, became so filled with modified drift during the sojourn of the surface beneath the ocean, that when it rose, the old rivers were compelled to seek new channels, and in some cases we have the amount of their erosion in the solid rock since that period. If this explanation be admitted, it follows that probably such cuts as the Niagara has made in the rocks below the cataract, in Genesee river, below Rochester, and between Mount Morris and Portage; in fact, all the ten cases referred to under the third inference, have been formed during the alluvial period: or since the close of the drift period. Nay, these old beds seem to have been filled with modified drift, and, therefore, the gulfs eroded since the last emergence of our continent from the waters, do by no means reach back to the drift period: that is, if we suppose the coarser and legitimate drift to have been produced while the continent was sinking. But since it is so difficult to fix the limits between drift and modified drift, we will regard the drift period as not closing till the work of erosion had commenced upon the rising continent. And even with such limits, what an immense period has elapsed since the period of the striation of rocks and the dispersion of the erratics closed, and the alluvial commenced.

But other facts in the history of alluvium correspond to the evidence which erosions present of the great antiquity even of the drift period. I refer specially to the vast deltas that have been pushed forward at the mouths of the large rivers of the globe, and the enormous accumulation of debris on the face of steep mountains. As mentioned in another part of this paper, the delta of the Mississippi, at its present rate of increase, must have required over 14,000 years to accumulate.

The growth and extent of coral reefs lead us to the same conclusion as to the length of the alluvial period. But perhaps the erosions of the surface form an argument for the earth's great antiquity more readily apprehended by men generally than any other.

ILLUSTRATIONS OF SURFACE GEOLOGY.

PART III.

TRACES OF ANCIENT GLACIERS

IN

MASSACHUSETTS AND VERMONT.

TRACES OF ANCIENT GLACIERS IN MASSACHUSETTS AND VERMONT.

WHOEVER is familiar with the phenomena of drift in this country, and has examined the effects of glaciers in the Alps, will be struck with the resemblance in most respects, and may perhaps infer a complete identity. I cannot, for the reasons already assigned in my paper on Surface Geology, adopt this opinion, but suppose it possible to distinguish between the two agencies by the following marks:

1. By the direction of the striæ and the position of the *stoss side* of the *roches moutonnes*. There is great uniformity and almost parallelism in the drift striæ in our country over wide surfaces. If, therefore, we find other striæ differing in direction very much from these, and the marks also having their stoss side very different as to the cardinal points, the presumption is strong that the more limited striæ were produced by glaciers.

2. Glacier striæ are limited to valleys, and proceed from the crests of the mountains outwardly, and the stoss side of the embossed ledges is always the upper side, that is, it faces up the valley, showing that the abrading body descended the valley. But drift striæ, although frequently found in the valleys, are also common upon the tops of the mountains; in this country with only one exception that I know of, viz: Mount Washington, in New Hampshire, which seems to have been above the agency.

3. The striæ of glaciers always descend from higher to lower levels, except in limited spots, where they may be horizontal. But drift striæ frequently ascend, the stoss side of hills and mountains, hundreds of feet high, being the lower side.

4. Drift is spread more or less promiscuously over most of the surface: but the detrital matter swept along by glaciers, occurs, either as lateral moraines along the sides of valleys, or accumulated in greater quantity where the valley makes a curve, or blocking up the valley as terminal moraines. In the latter case, however, the modern river occupying the valley, has usually worn away a part of the moraine, and during that process, it may be, has partially covered the other part with modified drift in the form of terraces.

Within the last five years I have had an opportunity to apply these principles in three widely separated countries, viz: Wales, Switzerland, and New England. I made a practical application of them in Scotland, but not with so satisfactory results.

As already stated in my paper on Surface Geology, when I went among the mountains of Wales, I had no recollection of the statements of the eminent geologists of Great Britain respecting its superficial deposits and markings: nor had I then been in a country of glaciers. I soon recognized erosions on the sides and bottoms of the valleys, quite similar to the drift markings with which I had been familiar in New England. But I found several differences. In Wales the grooves and striæ followed the valleys, I thought almost exclusively, radiating from the higher peaks of the Snowdonian range; nor did they reach to the top of the sides of the valleys, but the mountains above were ragged, not embossed as in the United States. I could not doubt that the erosions were produced by some force proceeding from the central and elevated parts of the country, following down the valleys, and in some spots I found that the slate rocks on the sides of the valley, had not merely been smoothed and scored, but knocked over, as if by a heavy body crowding against their upturned edges, and urging its way downwards. In short, I could not doubt that I had before me the marks of ancient glaciers. And I stated my convictions on the subject before the British Association for the Advancement of Science, where I was happy to have them confirmed by Professor Ramsay. That gentleman, I find, considers a glacier period to have preceded the drift period in Wales, and a second period of glaciers to have followed.

I make these statements to show how this subject has opened upon my mind. And for the same reason I will subjoin some details of the facts that fell under my observation in a sojourn of only a fortnight in Switzerland, respecting the former greater extent of its glaciers. The facts which I shall state can add nothing of importance to the more important ones adduced by Agassiz, Guyot, and others, and I suppose they have all been described. But I give them, both as a testimony in favor of the views of those gentlemen, and because they prepare the way for facts somewhat analogous, in New England.

As I ascended Mount Righi from the side of Lake Zug, far above the ruins of the famous Rossberg slide, certainly as high as the Stafflehaus, which, according to my barometer, is 4854 feet above the ocean, we find strewed along the steep side of the mountain, blocks of granite and gneiss, mixed with the Nagleflue, of which the mountain is composed. These crystalline boulders must have come from the higher parts of the Bernese Alps, and have constituted a lateral moraine. At least I can in no other way explain their occurrence in such a situation.

In ascending the Arve, from Geneva, we meet with remnants of former moraines far below existing glaciers. Some four or five miles before reaching Chamouny, we pass a defile, one or two miles long, where striæ and *roches moutonnes* are very distinct; the former conforming to the direction of the valley, and corresponding exactly to the effects of existing glaciers. How could I doubt that they originated in glaciers? If in North America I might strive to explain them by the action of huge icebergs, yet how useless to talk of icebergs in a narrow and retired valley of the Alps?

Most travellers who visit Chamouny ascend to the Flegere, on the northwest side of the valley. Everywhere in the vicinity of the Chalet there, the rocks are striated and rounded; and as well as I could judge, the same is the case several

hundred feet higher than the Chalet, which is 3500 feet above Chamouny, and 6925 feet above the ocean. This is much above existing glaciers in that vicinity. The striæ appeared to be directed down the valley of the Arve, and I could not doubt that this valley was once filled by a glacier to the height of nearly 4000 feet, which has entirely disappeared.

In passing from Chamouny to Martigny, through the Pass of Tete Noire, in the wild gorge that crosses the dividing ridge between the Arve and the Rhone, I noticed, several hundred feet above the gorge, which is 4200 feet above the ocean, distinct marks of a glacier that once descended towards the Rhone. The smoothed and striated wall must be over 5000 feet above the ocean.

On the way from Martigny to lake Leman, down the valley of the Rhone, although the mountains on either side are bold and rocky, I did not notice such distinct traces of glacial action as in the higher Alps. Yet in several places, especially where the ledges crowd into the valley so as to form gorges, they are rounded and furrowed. Some distance before reaching St. Maurice, I never saw so distinct examples of embossed rocks, and on them we can see distinctly that the abrading force was directed down the valley, since the most distinctly rounded side—*the stoss side*—of the embossed masses, faces up the valley. It seems as if we hardly needed stronger proof of an ancient glacier descending this valley.

I had no opportunity to trace the ancient glaciers of the Alps across the great valley of Switzerland to the Jura chain, as Professor Guyot has done. It did, however, appear to me, that for the most part the drift in that valley is modified drift; that is, has been comminuted and rearranged since it was originally produced by the glaciers. I feel quite sure that the terraces around lake Zurich and Lucerne, and along the Rhine, the Aar, and the Arve, lie above the drift and have been formed by the drainage of the country. Hence I infer that this valley, certainly as high as 2000 feet above the ocean, has been under water since the period of some of these ancient glaciers. If so, what else could such a body of water be, but the ocean?

Marks of ancient glaciers have been looked for in this country for a long period with deep interest: I mean, marks in distinction from those of drift, waiving the question whether the latter has originated from glaciers. I have never visited the culminating points of our country without an eye open for such phenomena. But until lately without success. I had supposed, however, and perhaps others have done the same, that the most probable place for such marks was among the White mountains of New Hampshire. Nor can I doubt that glaciers once existed there. But the nature of the rock is not well adapted to retain the traces either of these or of drift agency. It seems probable, moreover, that the ocean has stood above our continent since the glacier period, and the drainage has obscured the traces of glaciers, not merely by erosion, but by modifying the moraines. I apprehend, indeed, that this has been a chief reason, all over our country, why it has been so difficult to trace out the marks of glacier agency. I would not be absolutely certain that I have overcome this difficulty. Yet I have now discovered so many examples, not only of embossed and striated rocks, but of detrital accumulations, which I cannot refer to the drift agency, that I cannot resist the conviction that

they did originate in glaciers. The marks are not as striking here as in Wales, or Switzerland; but they are too numerous and obvious to be set aside as of no weight. I shall now proceed to give the details.

I have found all these markings upon the eastern slope of that broad range of mountains extending along the whole western side of New England, the one in Vermont, as the Green Mountains, and in Massachusetts, as Hoosac Mountain. This range in Vermont rises more than 4000 feet above the ocean: but in Massachusetts not over 2500 feet. My examinations have been mostly confined to Massachusetts, though it is obvious that Vermont promises to be a better field, because its mountains are higher. The west slope of this range of mountains is much the steepest, and the streams few and short. I have explored but a few of them, and have discovered no certain traces of glaciers, but I expect they will be found, especially in Vermont.

The annexed map, Plate VIII, extending as far as I have made any explorations, will give at a glance the principal facts which I refer to the action of former glaciers, and will make great minuteness of detail unnecessary.

My first discovery on this subject was quite accidental. I was exploring the gorge through which Little river debouches from the mountains, near the line between Westfield and Russell, into the valley of Connecticut river. As I passed along the north branch on the steep southerly face of Middle Tekoa, most distinct striæ and embossed rocks, arrested my attention, on a belt at least 140 feet wide vertically. As I knew the drift striæ in this region to run between north and south and S. 30° E., I was struck with this remarkable exception, and finding that the direction of the striæ corresponded with the course of the gorge through which Little river had cut its way, I was led to inquire whether the whole was not the effect of a glacier once descending through the valley of that river.

In 1853, in a Report to the Government of Massachusetts, I gave an account of this case, so far as it had then been explored, and of some other cases in the vicinity. I have continued, since that time, to follow up these inquiries and to extend them into other valleys in the same mountain range. The result is a still stronger conviction that the traces of ancient glaciers can be identified, though obscured by the subsequent operation of the drift and alluvial agencies. I say *subsequent* operation, and yet I confess that some of the striæ which I refer to glaciers, seem quite as recent as any found by the drift agency that I have ever seen; and really I do not feel quite satisfied which of these agencies was the earliest. Perhaps there were two periods of glaciers, one before, and the other subsequent to the drift.

The road from Westfield to Russell, just after crossing the line between the towns, rises rapidly along the south side of Little river, over ledges of mica slate, which have a dip almost 90°, and a strike not far from north to south. Till we reach the height of about 300 feet, these rocks exhibit that irregular yet smoothed surface characteristic of river action, in distinction from that of the drift agency, the ocean, or glaciers. And when we look down into the deep gorge of the river between Middle and South Tekoa, we infer at once that subsequent to the drift or glacier period, Little river has worn out its bed to that depth. But when we rise

higher and get a little beyond the farm house of Ichabod Blakesley, we meet, on the north side of the road, and close to it, very distinct striæ running almost exactly east and west, on a surface sloping easterly 10° or 12°. On the right the mountain, partly wooded and partly pasture ground, is very steep, and for 150 feet at least, the frequently uncovered rocks are striated, and much higher they exhibit evidence of having been abraded and embossed, though most of the *striæ* have disappeared. This evidence of a greater antiquity to the work of erosion as we ascend, is quite manifest. The highest part of the mountain, 314 feet above the striæ first named, is covered with forest, and the rock is rarely visible. Here we find several interesting boulders, of which I shall speak subsequently. But if we return to the striæ by the road side, and follow the road upwards no great distance, we shall reach the summit of the ridge, which runs southerly towards the river. Here we see at once, would be the spot where a glacier descending this valley, must have been most crowded, because on the opposite side of the river, South Tekoa rises up in the same manner as middle Tekoa, and the ridge was no doubt continuous across the river. Accordingly, in the road where it crosses this ridge and slopes somewhat towards the west, we find the abrasion to have been powerful, and the striæ numerous. We see, also, that the west side of the ridge is the *stoss* side, and if we follow the ridge upward above the road, we shall find almost to the summit, that the west or northwest side has been struck and smoothed, while the east is the lea side.

Returning to the point in the road where it crosses the ridge, and looking up the valley, we see that Little river comes in from the southwest, and a small stream from the northwest; and if a glacier once descended the former, a smaller one probably came down the latter, both uniting at this place, and of course this would be a point of severe pressure. If we turn easterly and look into the valley of the Connecticut, we shall see that South Tekoa extends easterly but a little way, so that the glacier, after passing this gorge, would find ample room to expand southerly, so that it would no longer crowd and striate Middle Tekoa. Accordingly, I have not found much evidence on the face of that mountain of glacier action more than half a mile or so east of the summit of this ridge.

I ought to mention, that the mountain known in the region as Tekoa, is a prominent peak of mica slate, on the north side of Westfield river, in the town of Montgomery. For convenience I call the mountain south of Westfield river, between that and Little river, in Russell, Middle Tekoa, and that south of Little river, in Granville, South Tekoa; although those names are not used in the vicinity. South Tekoa, by my barometer, is 1054 feet above the ocean, and Middle Tekoa about the same height. They all originally belonged to a continuous ridge, subsequently cut across by the rivers.

The north slope of South Tekoa lying directly opposite the striated ridge above described, in Middle Tekoa, is covered with a dense forest which prevents the rock from being seen to much extent. But though I saw no striæ, it was obvious that the west was the stoss side, as on the north side of the river.

All the facts in the vicinity, therefore, force the conclusion upon the geologist, that a glacier once descended the valley of Little river into the Connecticut valley.

But how is the region to the west, from which the glacier must have come? We see clearly that it is a mountainous region, and on consulting the Map of Massachusetts, based upon trigonometrical surveys, we find several mountains in a southwest, west, and northwest direction, high enough to have formed starting points for a glacier. Winchell's Hill, in Granville, lies in a southwest direction, a little over six miles distant, rising to the height of 1362 feet above the ocean, nearly 800 feet above the lowest of the glacier striæ, and 500 above the highest; giving a descent of nearly 100 feet in a mile. The same mountain extends nearly through Granville of nearly the same height, and its northern extremity is distant from the gorge in Russell only four or five miles. To the northwest of the spot, near the middle of Blanford, six and a half miles distant, we find Dug Hill, 1622 feet above the ocean. More to the west, and eight and a half miles from the gorge, Jackson's Hill, 1717 feet high: in the same direction, nearly 20 miles from the gorge, we find the Becket Station of the Trigonometrical Survey, which is 2193 feet high. Still more to the right, 22 miles distant, is French's Hill, in Peru, 2339 feet high. Indeed, the country rises to the west over a space of 90°, for nearly 20 miles: Hoosac mountain forming the culminating ridge; and Little river is one of the outlets through which glaciers, if they pressed downward from these mountains, would find their way to the Connecticut valley.

The inquiry, however, arose in my mind, whether these striæ, on the south slope of Middle Tekoa, were not the result of some modified form of the drift agency. And on examination, I did find on the west side of the Connecticut valley, that what I call drift striæ, instead of running north and south, as they usually do, turn southwesterly, south of Southampton, as much in some places, as S. 65° W. I suspected at first, either that these markings were produced by the glacier after it reached the Connecticut valley, or that the supposed glacier scratches were the result of drift agency operating up hill. But when I found that the stoss side of the glacier striæ was the west side, and that of the drift striæ was the northeast, both these suppositions were shown to be untenable, and I accounted for the southwest direction of the drift striæ by the expansion to the right, of the Connecticut valley south of Southampton. I think this the right interpretation of the facts: but I could wish to give them further examination. However they should be explained, it seems to me that they cannot invalidate the conclusion respecting the former descent of a glacier down the valley of Little river.

Still further to settle this question, I determined to visit the tops of the mountains north and west of the striated gorge, to ascertain the direction there of the drift agency. The country is very wild for the heart of New England, and excursions on foot can alone, in most cases, carry us to the summits. I first visited the hills in the southwest part of Russell, forming the north side of Little river; and there, about 1100 feet above the ocean, I found the rocks distinctly abraded and embossed by a force from the north: yet the striæ were mostly obliterated by the disintegration of the surface of the coarse mica slate. This was obviously a case of drift agency, and is so represented on the map.

The next locality to which I would refer, is two miles northwest of East Gran-

ville village, on the road to Blanford. Near the top of the hill, 1176 feet above Connecticut river, and 1240 above the ocean, the rocks are smoothed; and striæ, though almost obliterated, can be traced, running S. 10° E. and N. 10° W. On the same surface, also, especially the northern slope, I think I could discern striæ having a direction S. 60° W. and N. 60° E. Which set of striæ were made first, I found it difficult to ascertain. A little further north, 65 feet above the first named point, I found striæ running S. 20° E. and N. 20° W. But the cross striæ were not visible. That the stoss side in both cases, where the striæ approach nearest to the meridian, I could not doubt was the north side: but in the other case, I could not satisfy myself which side had been struck. I suspect that the latter were produced by the glacier that descended through the gorge on Little river, already described, which probably commenced much further to the west. The former striæ appeared to belong to the drift.

Returning now to the spot on the north side of Little river where the supposed glacier striæ exist, and ascending the steep face of the mountain northerly, we find, as already described, the striation evidently less and less distinct, though the abrasion is obvious enough, especially if we follow up the crest of the ridge. At the top of the first summit, 314 feet above the lowest striæ, that is, about 785 feet above the village of Westfield, and 956 above the ocean, we meet with several quite large and striking boulders, one of which measured 55 feet in circumference. One of our party, Mr. Henry B. Nason, of the Scientific Department in Amherst college, took a sketch of two of the most remarkable of these, which forms Plate X, Fig. 2. They are partially enveloped by shrubs and trees, and access to them is rather difficult; but they are well worth the trouble of visiting. I regard them as the result of drift agency rather than of glaciers, although it is possible that the glacier might once have overtopped this hill.

This eminence is one of the summits of Middle Tekoa, and it overlooks a wide extent of country to the northwest, from whence the drift agency came. To the northeast, however, other ridges of the mountain rise considerably higher. We passed to the north end of what may be called a middle ridge of the mountain, perhaps half a mile from the boulders, and where it begins to slope northerly towards Westfield river. Here the marks of drift action are very manifest in the rounding and abrasion of the rocks, and the north side was the stoss side. Generally the small striæ have disappeared; but in a few places I found grooves running S. 20° E. and N. 20° W. Towards the south end of the hill is quite an accumulation of boulders. The smoothed rocks show themselves occasionally as we descend the hill southerly, very nearly as low down as the highest of the rocks striated at right angles by the glacier. Indeed, the two agencies can be traced very near to each other in several places.

All the circumstances then at this spot seem to conspire to sustain the opinion, that either before or after the drift period, a glacier descended through the gorge of Little river, which has subsequently deepened its bed nearly 300 feet. The results of the three kinds of action, the fluviatile, the glacial, and the drift, are here in so close juxtaposition that one or two hours' walk will bring distinct examples of each under the eye; and although I have found analogous phenomena in other places, I

know of no other spot where the *ensemble* of the facts (except the moraines) are so distinct and near together.

But if a glacier once descended this valley, doubtless other valleys opening eastward from the same mountain range, must have been subjected to similar action. Guided by this inference, I have examined other spots where the outline of the surface seemed to promise most in this respect.

In the east part of Granville is a depression of the surface, forming a valley north and south, and bounded easterly by an elevation of considerable height, called Sodom mountain. This ridge is cut in two by a small stream, and a deep valley is formed, opening easterly into Southwick. It occurred to me that this might be such a gorge as a glacier might pass through. I accordingly found at its entrance, near the termination of the road, at a point 565 feet above Connecticut river, and 630 feet above the ocean, near the house of Mrs. Jones, that very distinct striæ on the mica slate run E. 20° S. and W. 20° N., pointing easterly directly into the gorge, and westerly to the high region from whence a glacier might have come. Unfavorable weather prevented me from penetrating far into the gorge, where no road exists; but I cannot doubt that we have here another example of glacier action.

The next region to which I directed my explorations, was on the north slope of the range of mountains lying between Little river and Westfield river, presuming from the course and lofty sides of the latter, that a glacier or glaciers may have descended that valley also. I followed an old turnpike road from Blanford to Westfield, through the north part of Russell, and found that it follows what looks much like an old abandoned river bed, or that of a glacier, perhaps both. At any rate, some agency had acted upon the up stream side of the ledges and rounded them; though the striæ are mostly obliterated by disintegration. The direction of this valley is nearly east and west, and where it joins the present bed of Westfield river, the south bank is distinctly striated. This would be near the spot where a glacier, descending this valley, would unite with one descending the Westfield river valley, and of course the pressure would be here at a maximum.

The east branch of Westfield river, which I believe is rather larger than the west branch, runs so nearly south, and consequently so nearly coincides with the course taken by the drift, that I apprehend, had a glacier once descended this branch, it would now be impossible to distinguish between the effects of the two agencies. That the up stream side is the stoss side, is quite obvious; but the work may have been done by drift as probably as by a glacier.

The west branch of this river, however, which has a direction from 30° to 40° S. of E. and N. of W., is more favorably situated for distinguishing between the agency of drift and a glacier. And yet it must be confessed that the direction of the drift agency on the mountains to the west of this river, if I have not confounded the effects with those produced by glaciers, is quite irregular, and sometimes gets round towards east and west, as far as 45°. But in the valley of Westfield river, I think I have found some other evidence of a descent of a glacier besides striæ.

The part of this river that I have examined with the most care, lies between the

junction of the east and west branches, at Chester village and Chester Factories, which are a little more than six miles higher up the stream. It passes over this distance almost at right angles across nearly perpendicular strata of mica slate, portions of which project occasionally, so as to form prominent objects against which a force pressing down the valley must have struck; and in fact most of the distance, especially its upper part, these exposed ledges appear to have been much abraded and by a force directed down the valley. I found, also, in at least three places, such accumulations of boulders, as could not be accounted for in any other way but by supposing them the moraines of glaciers. These are shown upon the map, Plate VIII. The first one, after leaving Chester Factories and going eastward, occurs a mile distant, on the south side of the river, lodged at the foot of a projecting hill, as indeed I have always found them. It would seem, that as the glacier passed such projections, which would form gorges, or at least obstructions on one side, the fragments borne along by it would be shaken off.

The second example is on the same side of the river, three and a half miles below the Factories. The third is on the north side of the river, near the house, occupied when I visited the spot, by Ethel Osborne. This I think is the best example. The large and for the most part angular fragments lie along the side of a hill that rises 125 feet above them, and they rise above the river perhaps 100 or 200 feet. The great size, angular form, and large amount of these fragments, struck me as rendering their glacier origin extremely probable, taken in connection with the rounded aspect of the projecting bluffs. The descent from the Factories to Chester village, however, by my aneroid barometer, is only 246 feet, or 41 feet in a mile, which gives a slope of only 0° 27′. This is more than double some of the slopes of ancient glacier action in the Alps. (*De la Beche's Geological Observer*, p. 269. Philadelphia, 1851.) It ought to be stated, that in several places along this valley, I found river action 150 feet above the present stream, so that the original slope may have been much modified. Besides, immediately west of Chester Factories, the mountains, whence the glacier must have come, rise much more rapidly, and the grade of the crooked valley, along which the Western railroad is carried, is sometimes as high as 90 feet to the mile. This upper part of the valley I have not examined carefully with reference to glacier action. But if a thick glacier came down from the high region west of the Factories, we can easily conceive its lower extremity to be pushed forward four miles upon a more moderate slope. For Becket, which lies at the summit of this elevated region, is more than 1200 feet above the Factories, and only five or six miles distant.

These were the first accumulations of detritus that I had met in our country that bore any satisfactory resemblance to the moraines of Alpine glaciers. Those that had been pointed out to me were composed of materials that had been extensively modified by water. And I ought to add, that those which I now refer to glaciers on Westfield and Deerfield rivers, have undergone some changes from the action of water, subsequent to that of glaciers. In some cases it is obvious that water has stood entirely or partially above the moraine and covered its surface at least, with rounded and sorted materials; so that terraces may frequently be seen partially resting upon the moraines. The same thing may be seen in the Alps. In

ascending the valley of the Arve, beyond Chamouny, we pass over an enormous moraine, probably once produced by the Mer de Glace, which moraine once blocked up the whole valley to the height of 150 or 200 feet, but the Arve has cut a passage through it on the north side, and while eroding its present bed, it formed several terraces on both banks to the height of 50 feet, which extend to the village of Argentiere. Beyond that place, another moraine blocked up the valley, and has been in like manner cut through by the river, and I thought I could see terraces above the barrier in the hamlet of le Tour, which I did not enter. These effects were produced in the Alps without any general submergence of the country, and therefore the moraines are but little obscured in their characters. In the great valley of Switzerland, which appears to have been beneath the ocean for a long time subsequent to the ancient widely extended glaciers, the masses of detritus, once probably moraines, have been much modified on their surface, but within retain more nearly the character of unchanged moraines.

In the same manner do the moraines which I am describing in Massachusetts appear to me to have been modified and obscured by the long-continued presence and the action of water, as the surface emerged from the deep. It is this fact that seems to me to have obscured the phenomena so much that I have long hesitated to admit the existence of genuine moraines among our mountains. But the cases which I describe in this paper, taking into account this subsequent modifying influence of water, I cannot but hope will bear the test of examination. I shall refer to others besides those on Westfield river; and I have reason to suppose that if it had been in my power to examine the valleys, I might multiply examples. I think, for instance, that they exist in the valley of Saco river among the White mountains; but they are not numerous or striking.

Deerfield river, between Florida and Deerfield, crosses the ridges of mica slate, talcose slate, and gneiss, more nearly in an easterly direction than does the Westfield river. From Shelburne falls to where it debouches into Deerfield meadows, the river occupies a deep and wild gulf, which is called the Ghor. Above Shelburne falls, through most of Charlemont, nearly ten miles, the valley is broader and is occupied by terraces a considerable portion of the way, as represented upon the map. The descent of the river thus far is moderate: but for four or five miles beyond, the lofty hills crowd closer upon the river and the descent is greater. This brings us to the Tunnel which is commenced for penetrating Hoosac mountain, and above this point, Deerfield river, which through Charlemont runs E. S. E., takes a nearly southwest direction. It comes down from Vermont, through one of the wildest gorges in New England, scarcely admitting of roads or cultivation. From the Tunnel the road passes northwesterly over Hoosac mountain, rising 1415 feet above the Tunnel, or 1860 feet above Shelburne falls, or about 2480 feet above the ocean. From this high ridge must a glacier have come, if one ever descended Deerfield river, in Massachusetts.

Accordingly on the east face of Hoosac mountain, I found striæ running N. W. and S. E. on a steep easterly slope, the mountain itself running nearly north and south. They may be very distinctly seen, passing of course obliquely down the mountain, at least 800 feet above the Tunnel, and although the drift striæ on the

top and west edge of the mountain have nearly the same direction, I have never seen any such as far below the summit of a steep hill as 600 feet on its lee side in any other place, and as I find other proofs of a glacier descending Deerfield river from this point, I have connected these striæ on the east face of the mountain with such a glacier.

As the Tunnel, whether ever completed or not, will always be a spot easily found, I make it a starting point in my description of glacier action. A mile or two north of the Tunnel, up Deerfield river, a projecting hill on the west side shows fluviatile action from 100 to 200 feet high, above which line the rocks are embossed, as they are all along the high hill on that side of the river. To do this, the force must have come from the N. N. E. down the valley of Deerfield river, or about at right angles to the direction of the drift striæ on the top of Hoosac mountain. Above this point I have never been able to force my way but once, and then I was unable to examine the hills to much height for want of time and the great difficulty of getting along. But below the Tunnel the river turns suddenly towards the east, and the hill around which it curves, is distinctly embossed at its top, and so indeed, more or less, are all the projecting points on each side of the river below the Tunnel to Charlemont, and perhaps, also, I might say, to Shelburne falls. For several miles east of the Tunnel the river is quite crooked and the adjoining hills very high and precipitous, so that a good opportunity is presented for observing the outlines of the projecting cliffs above the line where the river has acted, which, in some places, I find as high as 100 or even 200 feet; but in other places, the erosion seems to have been nothing since the striating and embossing period. Thus, one mile below the village of Charlemont (West Charlemont, which I believe is called the centre), the north bank to the very water's edge, and even beneath the stream, is finely striated: the striæ pointing directly down the stream, or a little south of east. According to my views, at such a spot the river has not deepened its bed at all since the glacier period. But where the current is rapid in Zoar and Florida, it is quite obvious that the bed has been deepened a good deal, and we do not find glacier or drift action within 100 or even 200 feet of the stream perpendicularly.

Cold river is a smaller branch of Deerfield river than that which comes in from Vermont, as just described. It starts in the northwest part of Florida, on the top and near the west side of Hoosac mountain, and runs diagonally, in a southeast direction, nearly across the town, and near the eastern slope of the mountain it turns more easterly, and empties into Deerfield river in the west part of Charlemont, some miles below the Tunnel. I followed this river through Florida, as nearly as the roads would permit. On its west side, not far from the middle of the town, I found striæ running S. 22° E. Further down the stream, where it turns more easterly, the striæ point S. 45° E. Still further down, and where the eastern slope of the mountain commences, the striæ are directed still more to the east, pointing in fact almost directly down Deerfield river, viz: S. 55° E. These facts certainly sustain the presumption that a glacier once descended this valley. They are shown, as well as may be, on the Map of Drift and Glacier Striæ.

In three places below the Tunnel, and within five miles of it, on Deerfield river,

I have found accumulations of boulders and detritus, which I venture to denominate moraines. The first is not far from a mile and a half below the Tunnel, and rises on the north side of the river to the height of 60 or 70 feet. A portion of the same materials may be seen south of the river, but less striking. The second case occurs on the north side of the river, just below the soapstone bed, or quarry, for it has scarcely been quarried. The third, of more doubtful character, is a little below Zoar bridge, and is, also, on the north side of the river. They have all received considerable modification from water in the manner already described, but are inexplicable without calling in some other agency, and that agency, if a glacier, affords a reasonable explanation.

If we take the whole distance from Shelburne falls, about 14 miles, the descent is but small, only as I made it, 445 feet, equal to 30 feet in the mile, and 0° 20′ *en arc*. As far as we find moraines, however, the slope is great enough I judge, for the advance of a modern glacier. But I do find some evidence in the striæ and rounded rocks, even to the falls, that the glacier extended the whole distance, and if thus far then doubtless through the Ghor, whose slope is greater. At any rate, it seems to me, that as far as the moraines occur we may presume upon the former existence of a glacier, although the direction of the striæ does not differ much from that of the drift agency where it swept over Hoosac mountain. But it ought also to be stated, that on the lofty hills of Rowe, Heath, Shelburne, Conway, and Hawley lying north and south of Deerfield river, the course of the drift striæ rarely varies more than 10° from the meridian, and this is almost at right angles to the force that striated and embossed the valley of the river.

Passing now to the vicinity of Shelburne falls, we find a tributary of Deerfield river coming in from the northeast, and called North Branch. The junction lies on the east foot of a lofty ridge, through which Deerfield river has cut its way. I felt a peculiar interest in examining the valley of North Branch, because a glacier might once have descended it, and if so, its course for some distance must have been from the N. E. to the S. W. I found such to be the fact most decidedly, as far as I have explored the valley. The striæ on both sides of the stream are very manifest in several places, and to the height on the west side where alone I measured them, of 400 feet at least. The rounded points of the ledges show conclusively that the abrading force struck the northeast side. This abrasion may be traced downward to the point of the mountain, where the tributary enters Deerfield river, and on the north side of the same mountain, we find marks of the force that swept down Deerfield river; the two forces having met at an angle greater than a right angle, as the map will show.

The high land that rises between these two rivers forms Mount Pocomtuck, which is almost 1800 feet above the ocean. And I find that the striæ, almost to the top of this mountain, run nearly N. E. and S. W., as along the North Branch. Hence, if produced by a glacier, it must have risen very high; so high in fact, as to have swept over most of the region east of Hoosac mountain. Indeed, I found the striæ on the high regions of Rowe and Heath to run generally from 5° to 20° W. of south. These facts, I confess, excite a doubt whether this force from the northeast was a glacier or an iceberg. But that is a very unusual direction in

New England for drift striæ: and I should be glad to study the phenomena further.

There are a few other tributary streams on the eastern slope of Hoosac mountain, which I should be glad to examine more carefully, with reference to this question of ancient glaciers. I cannot but feel, however, that I have pointed out facts enough to induce others to make further explorations; enough, also, I trust, to produce the belief that glaciers did once exist in these regions.

Gladly would I have carried these researches into regions beyond Massachusetts, where the probability is still stronger that traces of glaciers might be found. A single excursion into Vermont, however, is all I have been able to make. I have spent a little time upon the branches of the Queechy or Waterqueechee river, in Windsor county, Vermont. The branches of that river, that pass through the gold region of Vermont, run east and northeast, and I was anxious to determine if marks of a glacier could be found descending those valleys, since the direction is nearly 180° different from that of the striæ on North Branch, just described. The result of my examinations I have given at the top of the map, where I have added a sketch of the Queechee region on a scale larger than that of the map below. The intervening space in Vermont is well worthy of examination, though the direction of the streams is almost coincident with that of the drift agency.

The marks of ancient glaciers on the branches of the Queechee are not so decided, I think, as upon the rivers already described in Massachusetts. Yet taken together, they have produced the conviction in my mind that such a glacier once descended that river as far as Woodstock at least. In ascending that stream above that village, I found within a mile or so, accumulations of detritus on the north bank, such as I have referred to moraines. Several miles further west, just before entering the village of Bridgewater, I found a still more decided example. The detritus here once extended across the entire valley, but has been worn away by the river on one side, just as I have described in the vicinity of Chamouny, in Savoy. Water has in this case considerably modified the materials at the surface of the heap.

Beyond Bridgewater I followed for several miles, a branch of the river that comes in from Plymouth, in a northeast direction. The mountains along this stream are high, and in several places it was obvious that the southwest side was the stoss side: though the striæ are mostly obliterated. I afterwards followed up another branch of the river to the gold mine, in Bridgewater, and I thought I saw evidence here, also, of glacial action on the west side of the ledges, but the evidence was not very striking.

The highest point which I reached on the road to Plymouth was 450 feet above Woodstock, distant about 10 miles, and the gold mine is 820 feet above that place. These heights would give a moderate slope, but great enough for a glacier.

It would be desirable to follow the road beyond the gold mine to the top of the Green mountains, as Killington Peak lies in that direction, one of the highest points of these mountains, as much as 4000 feet above the sea. The highest point which I have mentioned above, viz: the gold mine, is only 1580 feet above the ocean.

I am aware that the details which I have given in this paper will impress the reader with the limited extent of my researches compared with the field that lies yet unexplored. I have endeavored, however, to visit those points most likely to afford satisfactory results. If I have done enough in so difficult a matter to stimulate younger and more vigorous explorers to push these investigations into all the Alpine districts of our country, my deficiencies will ere long be supplied, and what I now grope after in the twilight may be made to stand out in the clearness of day, and with the stability of established truth.

NOTE.—In looking over the preceding pages, as they have passed through the press, it has occurred to me that the few references which I have made to the many eminent men on both sides of the Atlantic, who have written upon Surface Geology, might possibly be imputed to an overweening opinion of the superior value of my own observations. I can hardly believe, however, after what I have said on page 34, that any will think me guilty of such folly; certainly not in respect to my few and unimportant observations upon Europe. The fact is, I had been much interested in New England with surface geology under the form of terraces and beaches, or in more general terms, as unmodified and modified drift, and I was anxious to see with my own eyes how nearly these phases of the phenomena in Europe agreed with those at home. But the thought never entered my mind, that I should seem to be exalting my own few and defective observations above those of the scores of eminent men, who have been studying similar phenomena. I referred to the labors of Mr. Chambers and Professor Ramsay, because I had followed so closely in their track. If others have looked at the subject from the same point of view, I am not aware of it. I hesitated much whether it were best to give these European facts, as well as those in our country out of New England, because they are so few and scattered, but not because I imagined I was ignoring or neglecting the labors of others. And they do seem to me sufficient to show an identity between certain phenomena of surface geology in widely separated regions.

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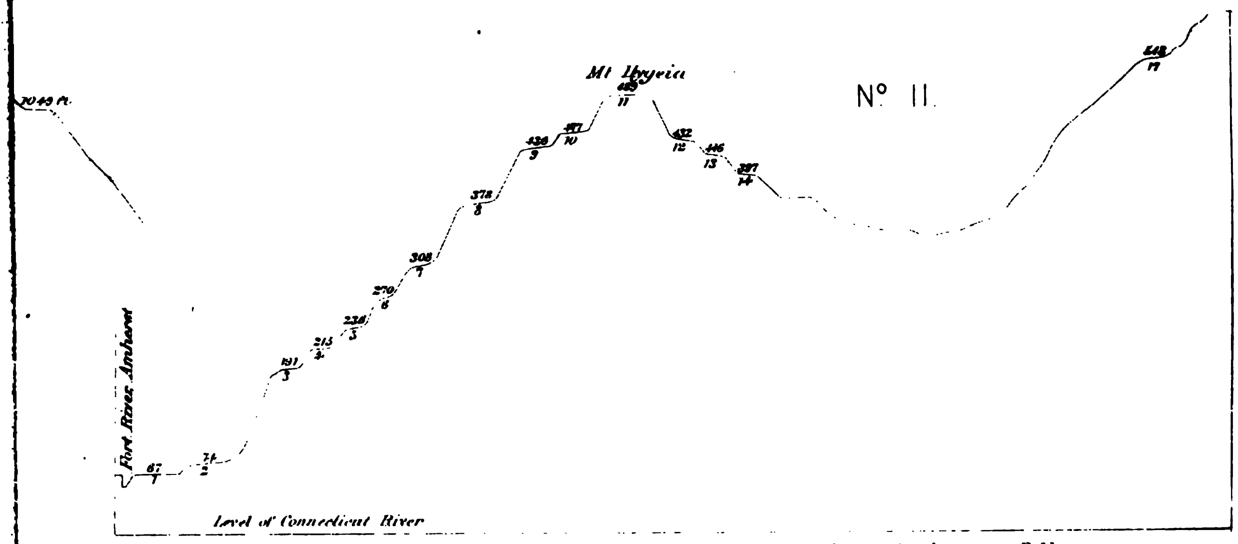
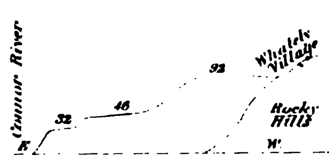


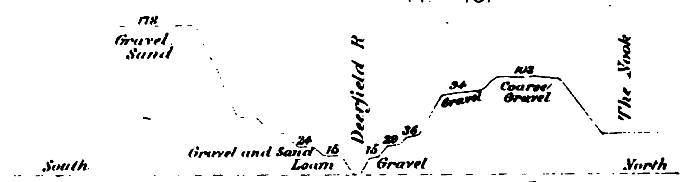
Terraces along the North Side of Fort River from Amherst to Pelham

N° 12.



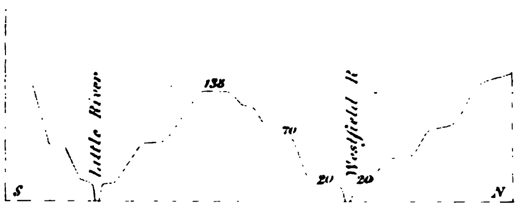
Section in Whately from Ct. River; west.

N° 13.



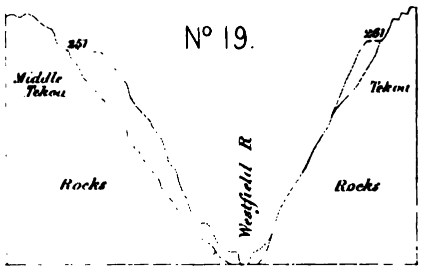
Section across Deerfield River at Foots Ferry near the entrance of the Ghor.

N° 18



Section across a tongue of Terraces in Westfield.

N° 19.



Gorge Terraces on Westfield River

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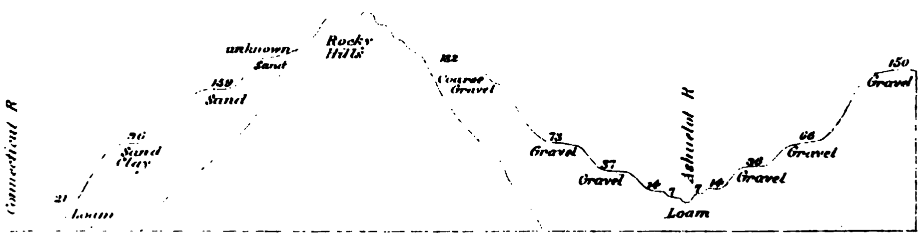
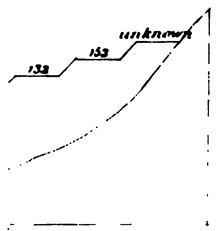
N° 25.



Section across Ashuelot R. in Hinsdale N. W. to the Connecticut.



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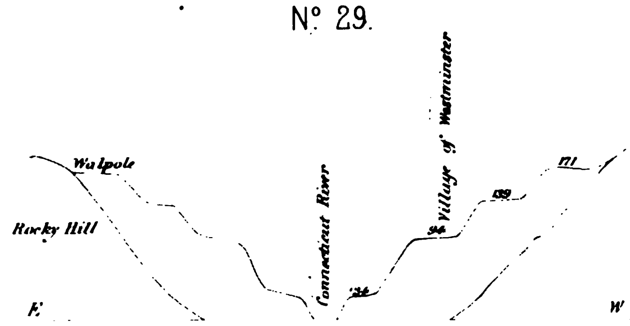
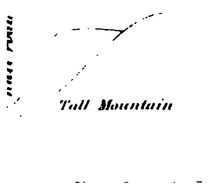
N° 29.



Section across Connecticut River from N W to S E from Westminster Vt. to Walpole N. H



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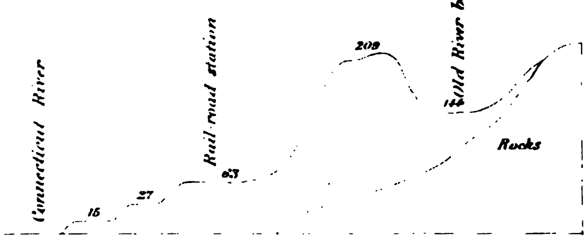
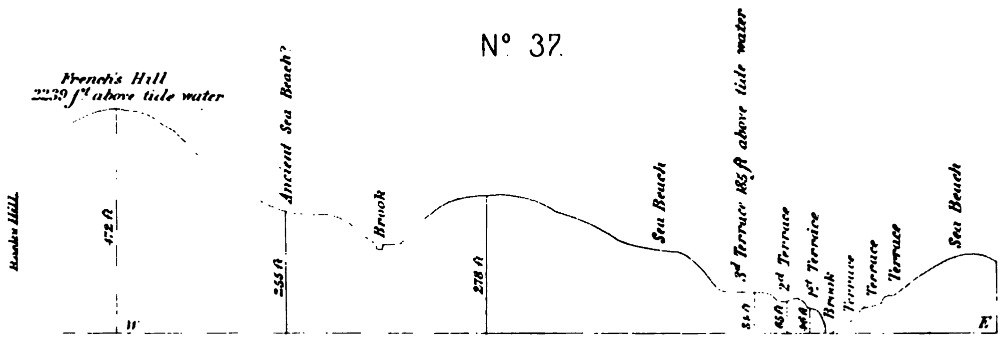
of the Falls.

N° 33



Section westward from Connecticut River at White River Junction.

N° 37.



Section from French's Hill in Peru easterly three miles. [Length of the base about three miles]

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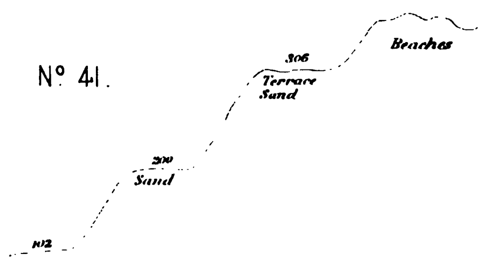
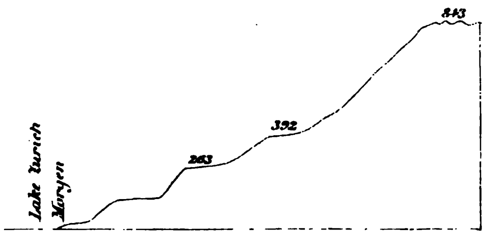
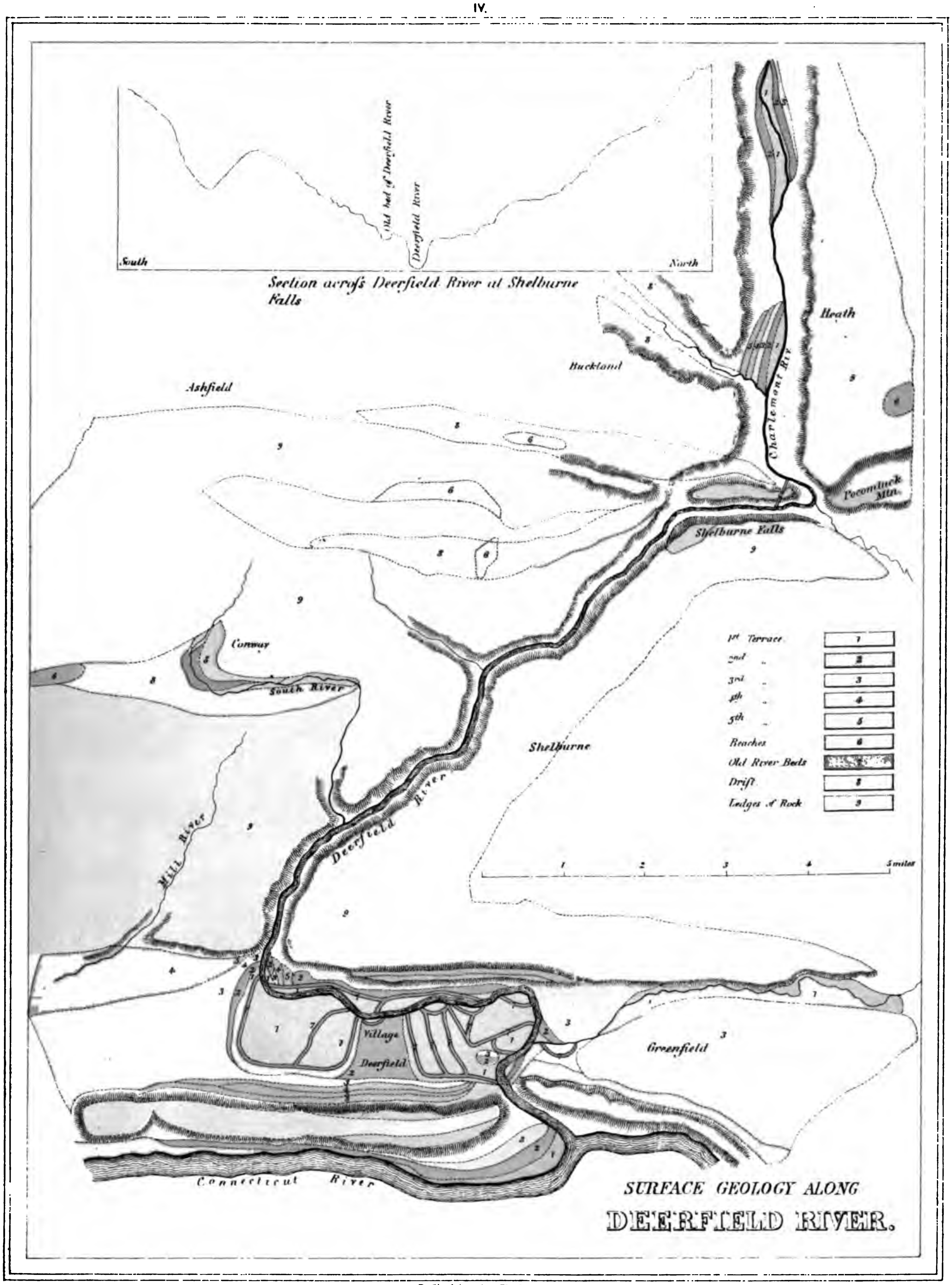


the Rhine from Rhinefelder towards

N° 42.



Section on the Western shore of Lake Zurich.



T. Sinclair's lith. Phil^a

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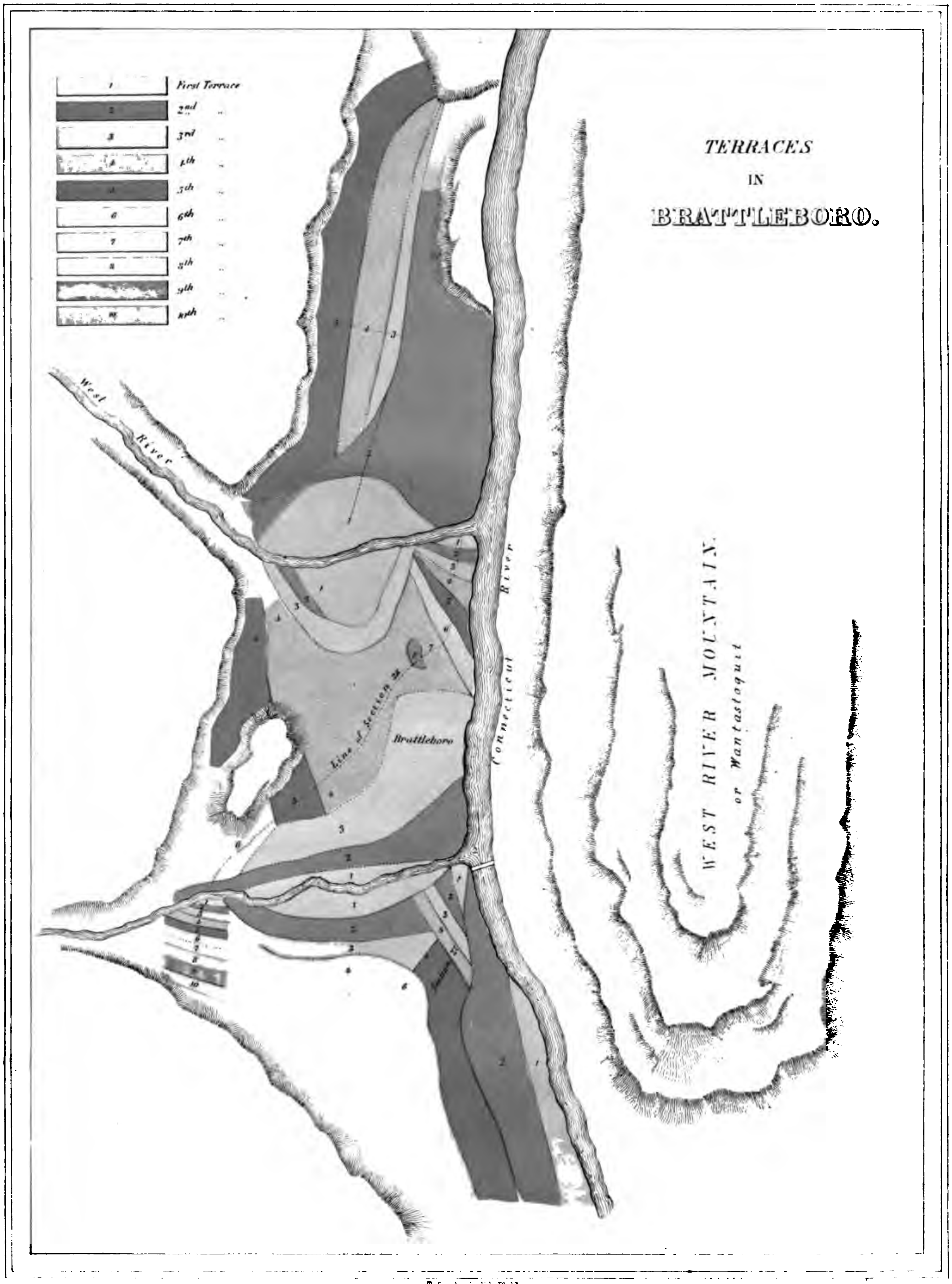

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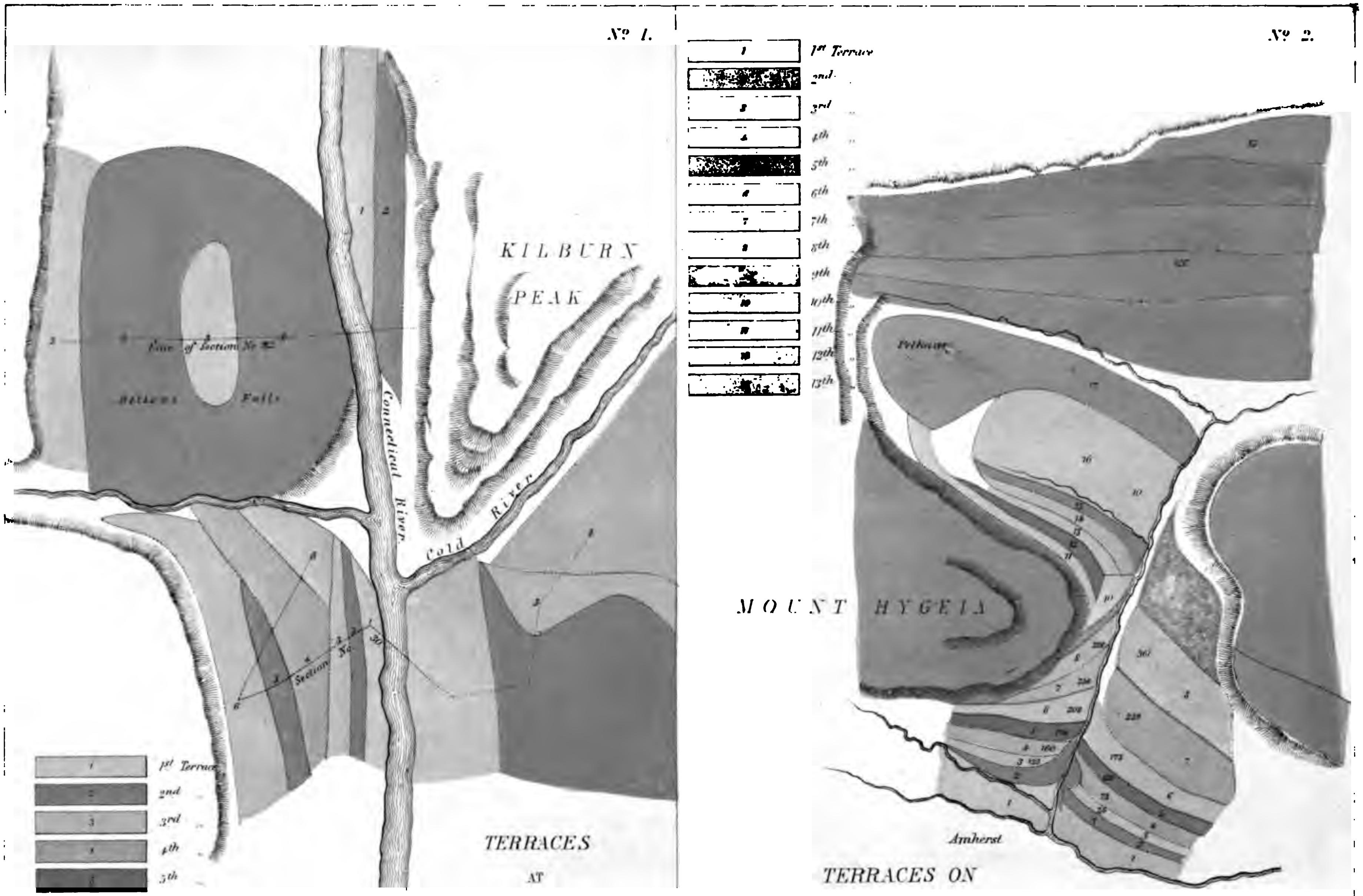
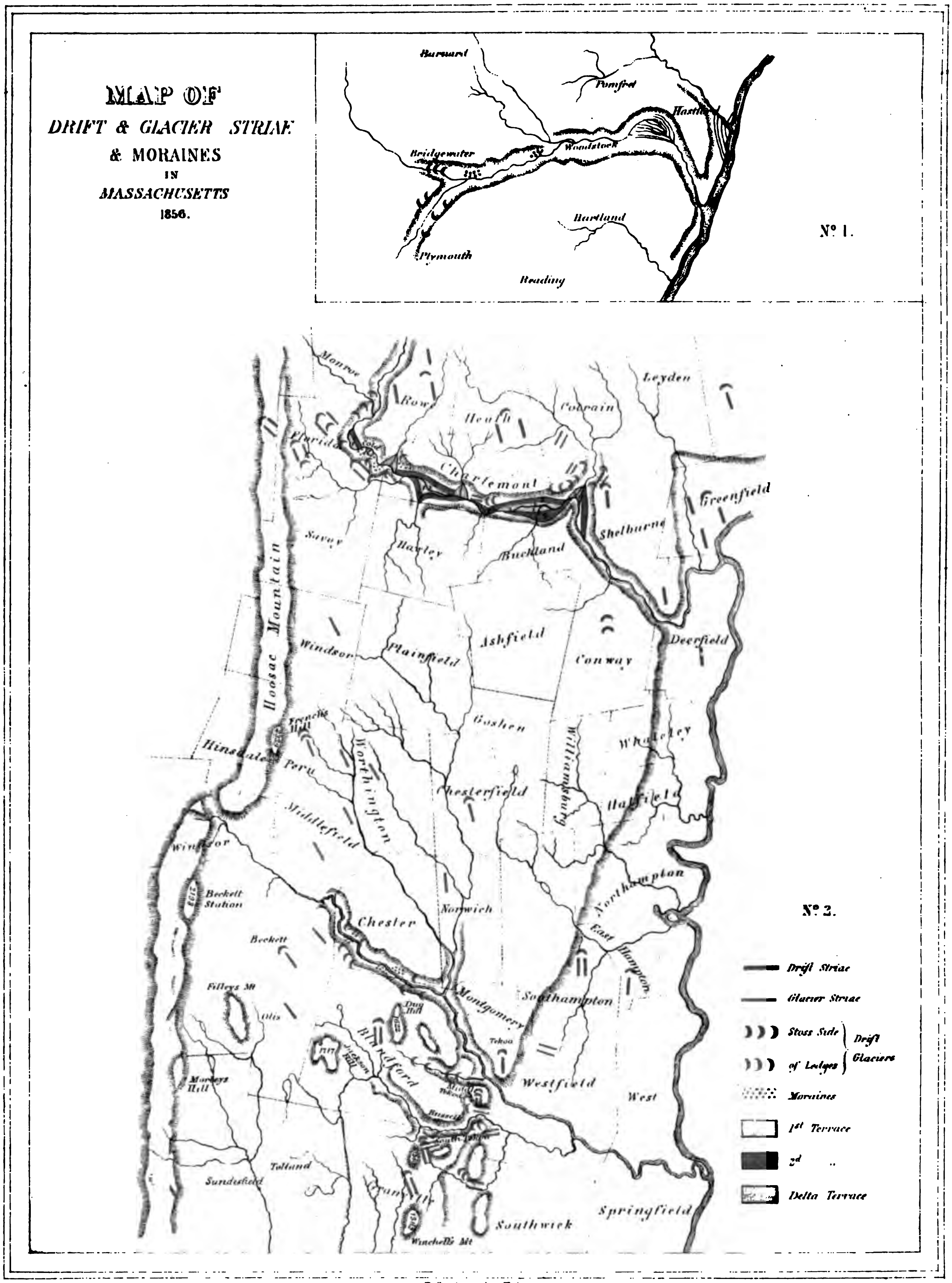


BELLOWS FALLS. FORT RIVER, PELHAM.


East Branch
West Hampton
Chester
Norwich
Southampton
Montgomery
Blandford
Westfield
Tekoa Mt.
Middle Tekoa
Russell
South Tekoa
Little River
Village
Granville
Munn's Brook
Westfield
Southwick
1st Terrace
2nd "
3rd "
4th "
5th "
6th Gorge Terrace
7th Old River Beds
TERRACES
ON
WESTFIELD RIVER.



T. Sinclair's lith Phila

IX.

Fig 1 Terraces in the gorge at Bellows Falls

Fig. 2 Terraces in Pelham

T. Sinclair's lith, Phila

X.

Fig. I. Terraces on Westfield River.
[at the Russell Station]

Fig 2. Boulders on Mount Tekoa
[viewed from the southwest.]

T. Sinclair's lith. Phil.a

Fig. 1. View of Eroded hills near Natal, S. Africa

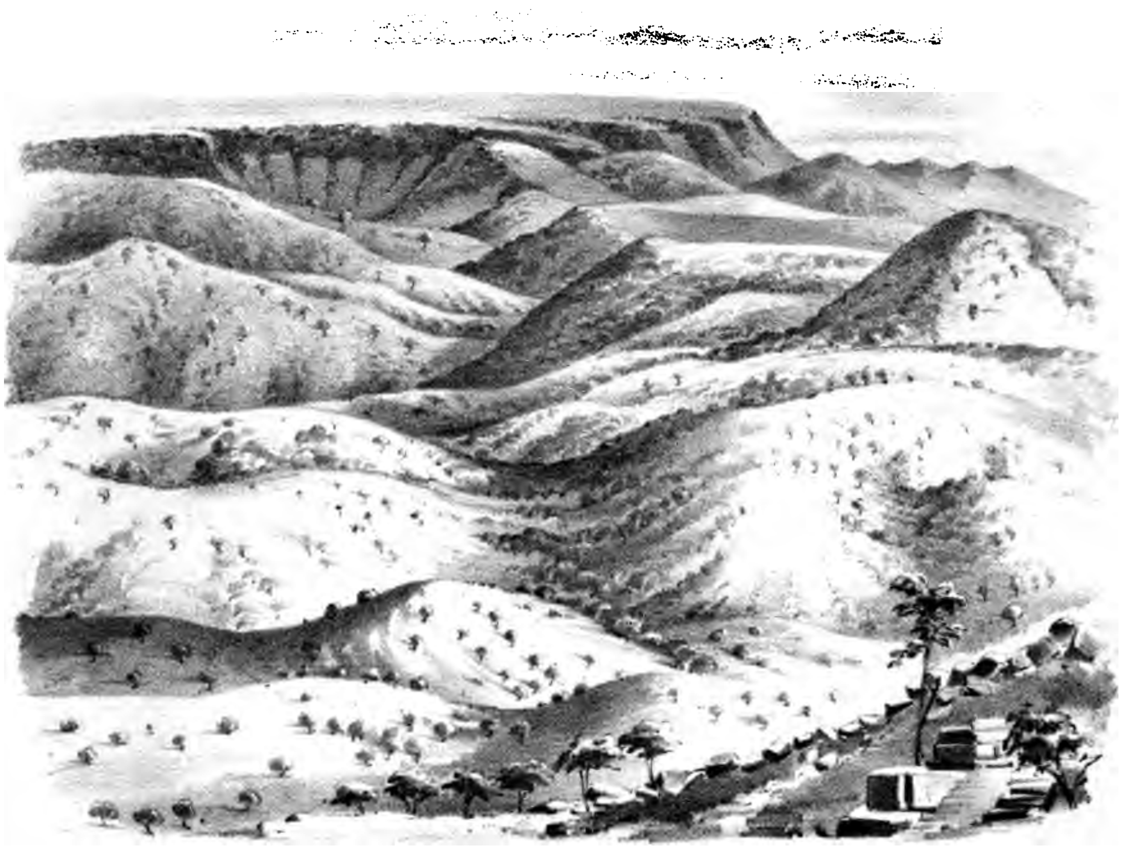


Fig. 2. Erosions on Mamana River, Natal, S. Africa

T. Sinclair's lith. Phil^a

Fig. 2.

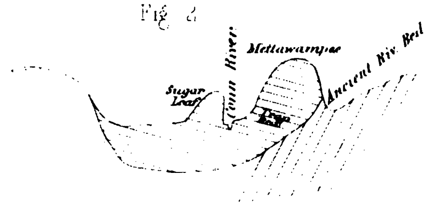
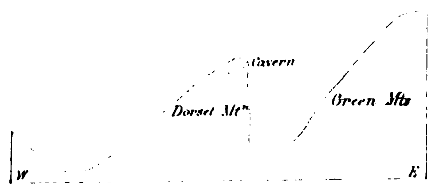


Fig. 5.



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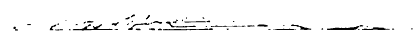

View of Sandalwood Island in the East Indian Archipelago

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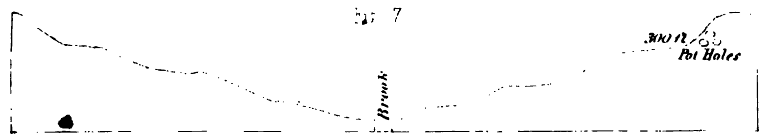
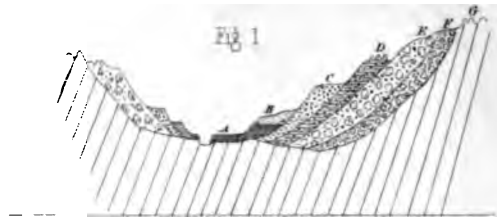


Fig. 9.

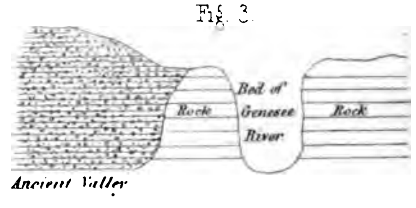
Cañon of Chelly.

Fig. 1.



Ideal Section of a Terraced Valley.

Fig. 3.



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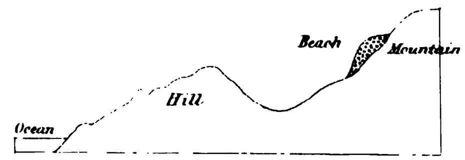

Fig. 8.

T. Sinclair's lith. Phila

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